Implications of Ecosystem Dynamics for the Integrated Management of the Eastern Scotian Shelf

Zwanenburg, K.C.T., A. Bundy, P. Strain, W.D. Bowen, H. Breeze,
S.E. Campana, C. Hannah, E. Head, and D. Gordon.

Science Branch
Fisheries and Oceans Canada
Ecosystem Research Division
Bedford Institute of Oceanography
P.O. Box 1006, 1 Challenger Drive
Dartmouth, NS B2Y 4A2

2006

Canadian Technical Report of Fisheries and Aquatic Sciences No. 2652

Fisheries and Oceans Canada
Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

2007-00214

Canadian Technical Report of
Fisheries and Aquatic Sciences 2652

2006

IMPLICATIONS OF ECOSYSTEM DYNAMICS FOR THE INTEGRATED MANAGEMENT OF THE EASTERN SCOTIAN SHELF

by

Zwanenburg, K.C.T., A. Bundy, P. Strain, W.D. Bowen, H. Breeze,
S.E. Campana, C.Hannah, E. Head, and D. Gordon.

Science Branch
Fisheries and Oceans Canada
Ecosystem Research Division
Bedford Institute of Oceanography
P.O. Box 1006, 1 Challenger Drive
Dartmouth, NS   B2Y 4A2
E-mail: Zwanenburgk@mar.dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2006.

Cat. No. Fs 97-6/2652E ISSN 0706-6457
PDF Version: Cat. No. Fs97-6/2652-PDF ISSN 1488-5379

Correct citation for this publication:

Zwanenburg, K.C.T., A. Bundy, P. Strain, W.D. Bowen, H. Breeze, S.E. Campana, C. Hannah, E. Head, and D. Gordon. 2006. Implications of ecosystem dynamics for the integrated management of the Eastern Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2652: xiii + 91 p.

TABLE OF CONTENTS

Executive Summary iv

Résumé viii

1.0 INTRODUCTION 1

2.0 ECOLOGICAL AND MANAGEMENT CONSIDERATIONS 2
- 2.1 Ecological Considerations 2
- 2.2 Management Considerations and Human Impacts 4

3.0 PHYSICAL AND OCEANOGRAPHIC SETTING 5
- 3.1 Currents and Water Masses 6
- 3.2 The Seabed 9

4.0 MAJOR ECOSYSTEM COMPONENTS 10
- 4.1 Phytoplankton 10
- 4.2 Zooplankton 12
- 4.3 Benthos 17
- 4.4 Fish and Invertebrates 19
- 4.5 Sharks 26
- 4.6 Marine Mammals 31
- 4.7 Seabirds 36
- 4.8 Other Biota 37

5.0 HUMAN IMPACTS 40
- 5.1 Environment Versus Exploitation 40
- 5.2 Bycatch 41
- 5.3 Impacts of Fishing Gear 48
- 5.4 Oil and Gas Exploration and Production 51
- 5.5 Marine Environmental Qualities and the Ecosystem 58

6.0 INTEGRATING CONCEPTS 61
- 6.1 Biodiversity 62
- 6.2 Trophic Interactions 63
- 6.3 Ecosystem Structure and Dynamics 63

7.0 REFERENCES 73

Appendix 1. Regional Work on Oil and Gas Issues to Date 90

Appendix 2. Science Requirements in Support of Oil and Gas Related Issues 91

EXECUTIVE SUMMARY

Zwanenburg, K.C.T., A. Bundy, P. Strain, W.D. Bowen, H. Breeze, S.E. Campana, C. Hannah, E. Head, and D. Gordon. 2006. Implications of ecosystem dynamics for the integrated management of the Eastern Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2652: xiii + 91 p.

Marine ecosystems are complex systems reflecting the dynamics between the environment, physical habitat, species and trophic interactions and human impacts. Many of the interactions within ecosystems or between human activities and ecosystem components can have non-linear or threshold effects such that small changes in one part of the system can have large effects elsewhere making prediction difficult and uncertain. Human impacts on marine ecosystems in the last century also mean that in most cases we do not have a clear picture of what the unexploited ecosystem looked like. We do however; have a growing understanding of the eastern Scotian Shelf ecosystem over more recent years.

The temperature, salinity and movement of the waters of the ocean have profound impacts on the distribution, growth and survival of marine organisms. Each organism has a particular range of temperature and salinity, which is optimal for its success. Water transports their food and oxygen, removes their wastes and also conveys the less active organisms from place to place.

The hydrographic environment of the eastern Scotian Shelf is governed largely by its location, near the meeting place of three major currents of the Northwest Atlantic; and its complex topography. The shelf-bottom topography consists of a series of submarine banks and cross-shelf channels along the outer shelf and basins and troughs along the central shelf that limit and guide the near-bottom flow. The eastern end of the Scotian Shelf consists mostly of cold fresh water from the Gulf of St. Lawrence and the Newfoundland Shelf and overall there is transport of water and organisms from the northeast towards the southwest. The eastern Scotian Shelf responds to the conditions in the Gulf of St. Lawrence and the Newfoundland Shelf, which are thought to reflect processes at more northerly latitudes. The deep basins on the central shelf are directly connected to the slope water, where the water properties are determined by interactions between the Labrador Slope Water Current and the Gulf Stream.

This response to different forcings leads to variations in the temperature, salinity and currents of the Scotian Shelf on many time scales from interannual to decadal. The gradual cooling of the bottom waters of the eastern shelf from the mid-1980s through the 1990s is an example of such decadal length variation that had a measurable impact on the structure and function of eastern Scotian Shelf ecosystems. The eastern shelf cooled from the mid 1980s to the early 1990s. This cold period is associated with increased abundance of cold-water fish (capelin, turbot) and invertebrates (snow crab, shrimp) usually more prevalent in colder Gulf of St. Lawrence and Newfoundland waters. Colder temperatures also lead to reductions in growth rates of demersal fishes. Changes in growth rates of species in response to changes in oceanographic conditions affect productivity, and therefore we must temper our expectations of yield in fisheries. In addition these physical changes will have impacts on the overall productivity and trophic structure of the supporting ecosystem. Changes in growth and distributions of fish and

invertebrates in response to changes in oceanographic conditions have significant implications for the overall trophic structure of the ecosystem.

The complex nature of the physical oceanographic features of the Scotian Shelf influences the patterns of abundance of phytoplankton. High-frequency spatial (kilometres) and temporal (days) variability in phytoplankton biomass is a common feature of the Scotian Shelf. Superimposed on this is a distinctive seasonal cycle of growth characterized by a conspicuous and widespread spring biomass peak, the spring "bloom", and a more diffuse fall bloom. This annual growth cycle may be as important in linking phytoplankton to production at higher trophic levels as the bulk (annual) primary production. In addition to the general current structure, early spring mixing (or stratification) is a critical physical property of the eastern Scotian Shelf, since it likely determines the timing of the spring bloom. Decadal trends in the spring bloom on the Scotian Shelf indicate that blooms start earlier now than they did in the 1960s and 1970s, and that spring blooms are now more intense and last longer.

The dynamics (timing and magnitude) of the principal phytoplankton grazers (zooplankton) will determine the extent to which phytoplankton production is transferred to the pelagic food chain or goes directly, as phyto-detritus, to the benthos. Although the phytoplankton and mesozooplankton communities cannot be managed, it is important to recognise that changes in response to variable hydrographic conditions can occur and that they can affect higher trophic levels through bottom-up processes. Disruptions in the normal timing of the phytoplankton bloom and Calanus finmarchicus reproductive and developmental cycles may have serious consequences for the survival of pre-settled groundfish and may influence the dynamics of subsequent recruitment. These sorts of changes cannot be controlled and must be recognized in the development and implementation of integrated management schemes.

The interaction of ocean currents and ocean bottom create a diverse array of habitats on the eastern Scotian Shelf. They range from areas that are regularly disturbed by tidal and other currents and where nutrients are relatively abundant to those that are very low energy, stable and where nutrients are scarce. Each of these habitat types is inhabited by a mix of organisms with unique life-history characteristics. The ability of these communities to withstand or to rebound from the impacts of human activities must inform the types of human activities that are acceptable in each of these habitat types. Disturbing the bottom with fishing gear, or by other activities, in an area that is regularly turned over by tidal currents will have significantly less long-term impact than that same activity through a deepwater coral reef.

Exploitation of the fisheries of the Scotian Shelf started in about 1560. By 1709 Nova Scotia was exporting about 10,000 t of cod and 4,000 t of mackerel and herring. By 1806 this had increased to about 40,000 t, and to over 100,000 t by the 1880s. In 1973 total landings of fish from the Scotian Shelf exceeded 750,000 t. In the early 1990s many of the east coast cod fisheries, including that of the eastern Scotian shelf, collapsed and were closed. For demersal fish species only the halibut longline fishery and some flatfish fisheries are currently operating on the Eastern Scotian Shelf. In addition to the overall reduction of biomass of commercially exploited fishes, the overall size structure and condition of the demersal fish communities has declined. Reduced numbers of larger fish can have significant negative impacts on long-term recruitment success; smaller fish produce fewer eggs that are less viable. This combination of effects may seriously impair the populations' ability to sustain or rebuild itself or a fishery. Since the collapse of the groundfish fishery, the fishery on the eastern Scotian Shelf has switched to lower trophic level invertebrates such as lobster, sea scallop, snow crab and shrimp. These species have increased in abundance since the collapse of groundfish, likely due to a combination of predator release and cooler water temperatures, and have created a very lucrative fishery for some.

Fisheries have many, and variable, ecosystem impacts including bycatch, which is the catch of non-target organisms during actual fishing operations. The overall impact of the trawl fisheries on the Scotian Shelf is not restricted to the commercially important species but includes in excess of 50 to 400 additional species. We estimate that they exert exploitation rates ranging from less than 1% of estimated biomass per annum to values in excess of 50% of estimated biomass. Impacts on fish communities include changes in community dominance, size spectra, and trophic structure. Ecosystem impacts of fisheries also include physical impacts on the habitat.

While there may be debate about the extent and long-term implications of the impacts of fishing, there is no doubt that the use of hydraulic clam dredges, otter trawls, scallop dredges and bottom-tending longlines is affecting (has affected) benthic habitat and communities within the ESSIM area.

Oil and gas exploration on the eastern Scotian Shelf may also have ecosystem impacts including accidental spills of hydrocarbons and drilling fluids since they have the potential to impact critical wildlife as well as harming significant components of the ecosystem. Accumulation of drilling components, hydrocarbons and other contaminants including produced water components in sediment and biota in the vicinity of offshore structures have the potential to impact critical wildlife as well as harming significant components of the ecosystem. Therefore, it is important to take management action to protect the structure, diversity and productivity of benthic habitat and communities where needed.

There is ample evidence that variability in the physical environment and lower trophic levels, variability in the abundance of high-level predators, and human activities can have significant and long-lasting effects on marine ecosystems. The eastern Scotian Shelf ecosystem has been profoundly altered and exhibits classic symptoms a trophic cascade and of "fishing down the foodweb". Comparison of two Ecopath models indicated that although total productivity and total biomass of the ecosystem remained similar between the early 1980s and late 1990s, there were changes in predator structure, trophic structure and energy flow, many of which were robust to uncertainty. There was a significant decrease in the biomass of demersal groundfish species and a significant increase in biomass of grey seals, small pelagic species, commercial crustaceans, and phytoplankton. The greatest change in the ecosystem is the switch from a demersal dominated system to a pelagic dominated system indicating a shift in trophic flow from the demersal to the pelagic side of the food web. The Pelagic:Demersal (P:D) ratio is an indicator of the negative effects of fishing.

Changes in biodiversity, manifested either as reduced species richness or changes in the proportional composition of the component species, can result in complex reorganizations of ecosystems such as we have seen on the eastern Scotian Shelf. Such reorganizations exhibit changes in production and stability and are mediated through changes in trophic interactions that can result in trophic cascades and shifts to undesirable states of the ecosystem. These reorganizations in turn have impacts on the richness and particular species composition of the reorganized ecosystem. Thus feedback mechanisms initiated by changes in biodiversity can cause further changes in biodiversity. The eastern Scotian Shelf has switched to an alternative state, dominated by small pelagics, invertebrates and seals. This state of hysteresis, whereby the previously abundant cod are kept at low levels of abundance, is maintained through a combination of cultivation-depensation effects, Allee effects and a massive reduction in the size structure of what remains of the cod population.

The management of human activities in marine ecosystems occurs against a dynamic biophysical backdrop as outlined above. Our understanding of how the ecosystem on the Scotian Shelf changes and how these changes manifest themselves is growing through recent studies and long term monitoring. However, we are aware that there are changes that occur over which humans have no control, but which have profound impacts on the structure and functioning of the system in which we carry out our activities. Although we have no control over such external factors we must know when they occur (or better yet when they are about to occur) so that our management actions can be adapted to the new conditions. We have seen, for example, that changes in the properties of water masses transported into the area can result in large and long-lasting changes in temperature over large areas of the Shelf and that these in turn have profound impacts on composition and productivity of an array of marine species. Such changes must be taken into account in the management of human activities. Not responding to such changes, by adjusting our expectations, is unrealistic and potentially harmful to the system itself. Equally, we must recognise the wide range of ecosystem impacts of fishing and other human activities such as oil and gas, and incorporate these wider impacts into management plans.

Adaptive management and reliance on expert opinion, or even best scientific guesstimates, will be a feature of integrated management for the foreseeable future. As further research is done, better indicators and more soundly based threshold values will undoubtedly emerge. The challenge for managers will be to develop management approaches that are sufficiently flexible to recognize the uncertainties in the underlying science and to incorporate new scientific information quickly as it becomes available.

Conceptual models of the structure and functioning of the Eastern Scotian Shelf provide a framework within which to identify those components of the system that are of particular concern to society and to guide the planning of research. A strong conceptual foundation is also needed to buffer long-term goals of the research from the short-term demands of the day. The framework must be specific enough to guide the first years of the plan, but general and flexible enough to remain relevant over the longer term and to respond to new, and yet unforeseen, management issues and to accommodate increased understanding of the ecosystem and its components.

SOMMAIRE

Zwanenburg, K.C.T., A. Bundy, P. Strain, W.D. Bowen, H. Breeze, S.E. Campana, E. Head, D. Gordon, and B. Petrie. 2006. Implications of ecosystem dynamics for the integrated management of the Eastern Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2652: xiii + 91 p.

Les écosystèmes marins sont des systèmes complexes qui reflètent la dynamique entre l'environnement, l'habitat physique, les interactions des espèces, les interactions trophiques et les effets dus à l'homme. Nombre des interactions à l'intérieur des écosystèmes ou entre des activités humaines et des composantes écosystémiques peuvent avoir des effets non linéaires ou seuils qui font en sorte que de petits changements dans une partie de l'écosystème peuvent avoir des effets importants ailleurs, ce qui rend les prévisions difficiles et incertaines. De plus, les effets des activités humaines sur les écosystèmes marins au cours du dernier siècle ont pour conséquence que dans la plupart des cas, nous ne pouvoir savoir clairement à quoi ressemblait l'écosystème non exploité. Nous avons toutefois approfondi nos connaissances sur l'écosystème de l'est du plateau néo-écossais au cours des dernières années.

La température, la salinité et la circulation des masses d'eau océaniques ont des effets considérables sur la distribution, la croissance et la survie des organismes marins. À chaque espèce correspond une plage particulière de températures et de salinités qui lui permet d'optimiser son succès. L'eau transporte la nourriture et l'oxygène nécessaires aux différents organismes, elle élimine les déchets de ceux-ci et elle assure les déplacements des organismes les moins actifs d'un endroit à un autre.

Les conditions hydrographiques de l'est du plateau néo-écossais sont fonction principalement de la topographie complexe et de l'emplacement de celui-ci, près du point de rencontre de trois courants importants de l'Atlantique Nord-Ouest. La topographie du plateau consiste en une série de bancs sous-marins et de chenaux qui le traversent à son bord externe ainsi qu'en des bassins et des fosses dans la partie centrale, qui limitent et orientent l'écoulement près du fond. L'extrémité est consiste principalement en de l'eau douce froide provenant du golfe du Saint-Laurent et du plateau de Terre-Neuve. Dans l'ensemble, l'eau et les organismes y sont transportés du nord-est vers le sud-ouest. Les conditions dans l'est du plateau néo-écossais dépendent des conditions dans le golfe du Saint-Laurent et sur le plateau de Terre-Neuve, qui sont considérées comme étant le reflet de processus à des latitudes plus élevées. Les eaux des bassins profonds du centre du plateau sont reliées directement aux eaux du talus, dont les propriétés varient en fonction des interactions entre le courant du Labrador et le Gulf Stream.

Cette réponse à différentes pressions donne lieu à des variations de la température, de la salinité et des courants à plusieurs échelles de temps, d'annuelle à décennale, sur le plateau néo-écossais. Le refroidissement graduel des eaux de fond de l'est du plateau, du milieu des années 1980 jusqu'à la fin des années 1990, est un exemple d'une variation à l'échelle décennale qui a eu un effet mesurable sur la structure et la fonction de l'écosystème de l'est du plateau. Cette partie du plateau a refroidi du milieu des années 1980 jusqu'au début des années 1990. Cette période froide est associée à une hausse de l'abondance des poissons (capelan et flétan noir) et

invertébrés (crabe des neiges et crevettes) d'eau froide, habituellement plus nombreux dans les eaux plus froides du golfe du Saint-Laurent et de Terre-Neuve. Les températures plus froides entraînent également une réduction du taux de croissance des poissons de fond. Les variations du taux de croissance de certaines espèces à la suite de changements dans les conditions océanographiques ont une incidence sur la productivité, et, par conséquent, nous devons ajuster nos attentes quant au rendement des pêches. De plus, ces changements physiques auront des répercussions sur la productivité globale et la structure trophique de l'écosystème. Les variations sur le plan de la croissance et de la répartition des poissons et des invertébrés résultant de changements dans les conditions océanographiques ont des conséquences importantes pour la structure trophique globale de l'écosystème.

La nature complexe des caractéristiques océanographiques physiques du plateau néo-écossais a une incidence sur l'abondance du phytoplancton. Une grande variabilité spatiale (en kilomètres) et temporelle (en jours) de la biomasse phytoplanctonique est courante sur le plateau néo-écossais. À cette grande variabilité s'ajoutent un cycle saisonnier de croissance particulier caractérisé par un pic de biomasse bien évident et étendu au printemps, la prolifération printanière et une prolifération automnale plus diffuse. Ce cycle annuel de croissance est peut-être aussi important pour relier le phytoplancton à la production aux niveaux trophiques supérieurs que la production primaire (annuelle) à grande échelle. En plus de la structure générale des courants, le mélange printanier précoce (ou stratification) est une propriété physique essentielle de l'est du plateau néo-écossais, puisqu'il détermine probablement le moment de la prolifération printanière. La tendance décennale des proliférations printanières sur le plateau indiquent qu'elles débutent maintenant plus tôt que dans les années 1960 et 1970, et sont maintenant plus importantes et durent plus longtemps.

La dynamique (moment et nombre) des principaux organismes planctonophages (zooplancton) déterminera l'ampleur du transfert de la production phytoplanctonique à la chaîne trophique pélagique et du transfert au benthos, directement sous forme de déchets phytoplanctoniques. Bien que les communautés mésozooplanctoniques et phytoplanctoniques ne peuvent être gérées, il est important de reconnaître que des changements peuvent se produire à la suite de variations de conditions hydrographiques et qu'ils peuvent avoir une incidence sur les niveaux trophiques supérieurs par le biais de processus ascendants. La perturbation de la période normale de la prolifération du phytoplancton et des cycles de développement et de reproduction de *Calanus finmarchicus* peut avoir des conséquences fâcheuses pour la survie des poissons de fond déjà établis ainsi qu'un effet sur la dynamique du recrutement subséquent. Ces types de changements ne peuvent être régulés et doivent être pris en considération lors de l'élaboration et de la mise en œuvre de plans de gestion intégrée.

L'interaction des courants océaniques et du fond marin crée une vaste gamme d'habitats dans la partie est du plateau néo-écossais, de zones qui sont perturbées régulièrement par les courants de marée et d'autres courants et où les éléments nutritifs sont relativement abondants à des zones stables, de faible énergie et pauvres en éléments nutritifs. Chacun de ces types d'habitat est occupé par un mélange d'espèces aux cycles vitaux uniques. La capacité des communautés de ces espèces à résister aux effets des activités humaines ou à se rétablir à la suite de tels effets doit être prise en considération lors de la détermination des types d'activités humaines qui sont acceptables dans chacun de ces types d'habitat. La perturbation du fond par des engins de pêche, ou dans le cadre d'autres activités, dans une zone qui est régulièrement soumise à l'action des courants de marée aura une incidence à beaucoup moins long terme que dans une zone en eaux profondes où un récif de corail est présent.

L'exploitation des ressources halieutiques sur le plateau néo-écossais a débuté vers 1560. En 1709, la Nouvelle-Écosse exportait environ 10 000 t de morue et 4 000 t de maquereau et de hareng. Ces exportations étaient d'environ 40 000 t en 1806 et elles étaient supérieures à 100 000 t dans les années 1880. En 1973, le total des débarquements de poissons provenant du plateau néo-écossais a dépassé 750 000 t. Au début des années 1990, nombre de pêches de la morue de la côte Est, y compris celle de l'est du plateau néo-écossais, se sont effondrées et ont été fermées. Dans le cas des poissons de fond, seules la pêche du flétan à la palangre et certaines pêches de poissons plats sont actuellement ouvertes dans l'est du plateau. La biomasse des poissons pêchés à des fins commerciales a connu une baisse globale, tout comme la structure de taille et l'état des communautés de poissons de fond. Une diminution du nombre de poissons de grande taille peut avoir des effets négatifs importants sur le succès du recrutement à long terme, les plus petits poissons produisant moins d'œufs et ceux-ci étant moins viables. Cette combinaison d'effets peut nuire considérablement à la capacité de résistance ou de rétablissement des populations ou à une pêche. Depuis l'effondrement de la pêche du poisson de fond, la pêche dans l'est du plateau néo-écossais a pris un virage, pour cibler aujourd'hui les invertébrés de niveaux trophiques inférieurs, comme le homard, le pétoncle géant, le crabe des neiges et les crevettes. L'abondance de ces espèces a augmenté depuis l'effondrement des populations de poissons de fond et ce, probablement en raison de la baisse du nombre de prédateurs et de la température des eaux. Ces espèces font maintenant l'objet de pêches très lucratives pour certains pêcheurs.

Les pêches, y compris les prises accessoires (c.-à-d. les organismes non visés capturés dans le cadre d'activités de pêche ciblées), ont de nombreux effets variables sur les écosystèmes. L'impact global des pêches au chalut sur le plateau néo-écossais n'est pas limité aux espèces importantes sur le plan commercial, mais il touche de 50 à 400 autres espèces. Nous estimons que le taux d'exploitation varie de moins de 1 % à plus de 50 % de la biomasse estimée par année. Les répercussions sur les communautés de poissons comprennent les changements dans la dominance, le spectre de taille et la structure trophique des communautés. Les répercussions des pêches sur les écosystèmes comprennent également les effets physiques sur l'habitat.

L'ampleur et les conséquences à long terme des répercussions de la pêche peuvent faire l'objet de débats, mais il ne fait aucun doute que l'utilisation de dragues hydrauliques pour la pêche de bivalves fouisseurs, de chaluts à panneaux, de dragues à pétoncles et de palangres a des effets sur l'habitat et les communautés benthiques dans la zone de gestion intégrée de l'est du plateau néo-écossais (GIEPN).

Les activités d'exploration pétrolière et gazière, y compris les déversements accidentels d'hydrocarbures et de fluides de forage, peuvent également avoir des répercussions sur l'écosystème de l'est du plateau néo-écossais puisqu'elles peuvent avoir des effets sur des espèces essentielles et endommager des composantes importantes de l'écosystème. Il en va de même de l'accumulation de composants de forage, d'hydrocarbures et d'autres contaminants, y compris les composants de l'eau produite, dans les sédiments et le biote à proximité des structures en mer. Par conséquent, il est important de prendre des mesures de gestion appropriées afin de protéger, au besoin, la structure, la diversité et la productivité de l'habitat et des communautés benthiques.

Il existe de nombreuses preuves du fait que les variations dans le milieu physique et les niveaux trophiques inférieurs, les variations de l'abondance des prédateurs supérieurs et les activités humaines peuvent avoir des effets importants et à long terme sur les écosystèmes marins. L'écosystème de l'est du plateau néo-écossais a été profondément modifié et il présente un cas classique d'épuisement successif, de haut en bas, des niveaux trophiques par la pêche. La comparaison de deux modèles Ecopath révèle que, même si la productivité et la biomasse totales de l'écosystème sont demeurées semblables entre le début des années 1980 et la fin des années 1990, des changements se sont produits dans la structure de prédation, le réseau trophique et le flux d'énergie, dont plusieurs sont robustes face à l'incertitude. La biomasse des espèces de poissons de fond a connu une baisse importante, tandis que la biomasse des phoques gris, des petites espèces pélagiques, des crustacés d'importance commerciale et du phytoplancton a connu une augmentation marquée. Le plus grand changement survenu à l'intérieur de l'écosystème est le passage d'un système dominé par les poissons de fond à un système dominé par les espèces pélagiques, ce qui indique une transition du flux trophique du côté démersal au côté pélagique de la chaîne trophique. Le rapport entre les espèces pélagiques et les espèces de fond constitue un indice des effets néfastes de la pêche.

Des changements dans la biodiversité, qui se présentent soit sous la forme d'une réduction de la diversité spécifique ou de variations de la proportion des espèces présentes, peuvent entraîner des réorganisations complexes des écosystèmes comme nous l'avons constaté dans l'est du plateau néo-écossais. De telles réorganisations entraînent des changements sur le plan de la production et de la stabilité et se produisent par l'intermédiaire de variations des interactions trophiques qui peuvent donner lieu à des épuisements successifs et à une dégradation de l'état de l'écosystème. Ces réorganisations ont pour leur part des répercussions sur la diversité et la composition en espèces de l'écosystème. Ainsi, les mécanismes de rétroaction déclenchés par les changements dans la biodiversité peuvent entraîner d'autres changements semblables. L'est du plateau néo-écossais est maintenant dans un état différent, dominé par les petits pélagiques, les invertébrés et les phoques. Cet état d'hystérésis, dans lequel l'abondance de la morue, auparavant élevée, est gardée à de faibles valeurs, est maintenu par le biais d'une combinaison d'effets dépensatoires et culturaux, d'effets d'Allee et d'une amenuisement considérable de la structure de taille de ce qui reste de la population de morues.

Ainsi, la gestion des activités humaines dans les écosystèmes marins est effectuée dans un contexte biophysique dynamique, tel que décrit précédemment. Des études et une surveillance à long terme nous permettent d'accroître notre compréhension de l'évolution de l'écosystème de l'est du plateau néo-écossais et de la façon dont ces changements se produisent. Nous sommes toutefois conscients qu'il y a des changements sur lesquels l'homme n'a aucun contrôle et qui ont d'importantes répercussions sur la structure et le fonctionnement de l'écosystème dans lequel nous menons nos activités. Bien que nous n'ayons aucune influence sur de tels facteurs externes, nous devons savoir quand ils se produisent (ou, encore mieux, quand ils sont sur le point de se produire) de façon à ce que nos mesures de gestion puissent être adaptées aux nouvelles conditions. Nous avons vu que, par exemple, des changements dans les propriétés des masses d'eau transportées dans le secteur peuvent donner lieu à des changements importants et à long terme de la température dans de grandes régions du plateau et que ceux-ci, à leur tour, ont des effets considérables sur la composition en espèces et sur la productivité d'une gamme d'espèces marines. De tels changements doivent être pris en considération dans le cadre de la gestion des activités humaines. Ne pas réagir à de tels changements, en modifiant nos attentes, ne constitue pas une option réaliste et risque de causer des dommages à l'écosystème en soi. De même, nous devons reconnaître la vaste gamme d'effets que la pêche et d'autres activités humaines, comme les activités pétrolières et gazières, ont sur les écosystèmes et tenir compte de ces effets à grande échelle dans les plans de gestion.

La gestion adaptative et la confiance en l'opinion d'experts, ou même en les meilleures estimations scientifiques approximatives, seront un aspect de la gestion intégrée dans un avenir prévisible. Au fil de la recherche, de meilleurs indices et valeurs seuils seront certainement établis. Le défi que les gestionnaires devront relever consistera à mettre au point des approches de gestion suffisamment souples pour reconnaître les incertitudes dans la science sous-jacente et à intégrer les nouvelles informations scientifiques dès qu'elles seront disponibles.

Les modèles conceptuels de la structure et du fonctionnement de l'est du plateau néo-écossais fournissent un cadre de travail permettant d'identifier les composantes de l'écosystème qui préoccupent particulièrement la société et d'orienter la planification de la recherche. Un fondement conceptuel solide est également nécessaire pour isoler les objectifs à long terme de la recherche des demandes du jour à court terme. Le cadre doit être suffisamment précis pour servir de guide lors des premières années du plan, et il doit être suffisamment général et souple pour demeurer pertinent à long terme, pour permettre de répondre aux questions nouvelles, et encore imprévues, en matière de gestion et pour tenir compte des nouvelles connaissances relatives à l'écosystème et à ses composantes.

1.0 INTRODUCTION

The Eastern Scotian Shelf (Figure 1) Integrated Management initiative (ESSIM) is a DFO National pilot project that has been tasked with developing an integrated management plan for the sustainable use and protection of the aquatic resources on the Eastern Scotian Shelf. The project is led by the Maritimes Region Oceans and Habitat Branch of the Department of Fisheries and Oceans (DFO), who have made significant progress in implementing the transparent and co-operative approach to integrated management (IM) that the Oceans Act requires. In late 2003, as the ESSIM initiative was preparing for its operational phase, the ESSIM Science Working Group (ESWG) was formed to facilitate a more collaborative working relationship between Science Branch and Oceans and Habitat Branch and to provide a mechanism for science input to the IM process.

Since 2001, Science Branch has been developing a framework for identifying ecosystem management objectives for the protection and sustainable use of marine ecosystems, and DFO has adopted an objectives-based approach to formulating both human use objectives and ecosystem objectives, also referred to as 'conservation' objectives, to distinguish them from human use objectives (e.g. DFO, 2001; O'Boyle et al., 2004). The Oceans Act also commits DFO to following an ecosystem based approach to integrated management. The first and most significant task given to the ESSIM Science WG was to develop operational conservation objectives for the Eastern Scotian Shelf (ESS) based on material developed by the multistakeholder ESSIM community and other science input.

As it began work on developing operational ecosystem objectives, the ESWG realized that it was necessary to understand the nature and functioning of the ESS ecosystem to provide a context for the development of objectives and a means for integrating the many candidate objectives and for assigning priorities to them. Some of this background material had already been prepared, including a description of the structure of the ESS ecosystem (Breeze et al., 2002) and a review of how the ESS ecosystem has changed over the last several decades (DFO, 2003, Zwanenburg 2003, Zwanenburg et al 2002,). However, an ecological assessment of how the ecosystem works was not available. This report provides such an ecological assessment by focusing on; the interactions between different components of the ecosystem, between the ecosystem components and their habitat, and between the ecosystem and major human activities. The scope of the report is the offshore (depths greater than 30 m) portion of the Eastern Scotian Shelf; separate initiatives will address the management of the coastal zone. This version of the report is highly technical, and is aimed at those specialists preparing the draft operational objectives. Other versions of the report will be prepared for the use of ocean managers and other stakeholders.

In the following four sections of the report we first present an overview of the ecological and management considerations that provide the context and broad scale objective of the ESSIM integrated management initiative. This is followed by a section on the physical environment within which the management of human activities takes place. Emphasis here will be on major dynamic and structural features of the water column and ocean bottom. These in turn are followed by a relatively detailed discussion of the biotic components of the ESS with particular emphasis (where this is known) on the interaction of the biotic and abiotic components and how these interactions are modified by human activities. We then provide an overview of the major human activities that are currently operative on the ESS with some historical perspective. Finally in the section on Integrating Concepts (Section 6) we provide an overview of the major trophodynamic features of the ESS ecosystem(s).

2.0 ECOLOGICAL AND MANAGEMENT CONSIDERATIONS

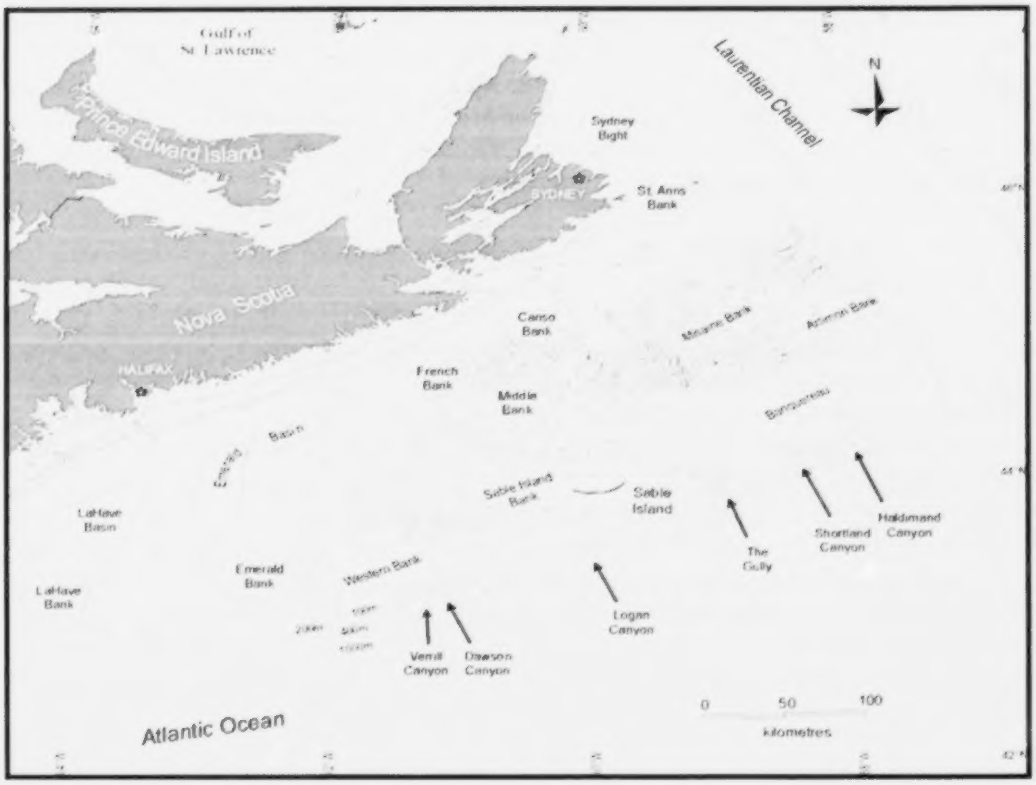


Figure 1. Bathymetry and place names of the eastern Scotian Shelf.

2.1 ECOLOGICAL CONSIDERATIONS

In considering the integrated management of the Eastern Scotian Shelf (Figure 1), it is important to understand the ecological context within which such management is embedded. Natural interactions between different components of the ecosystem and between these components and their habitat are complex. The habitat itself is subject to significant natural variability due to varying external drivers like large ocean currents and atmospheric climate. To be successful, a management strategy must be aware of these natural interactions and variability and understand how human activities influence this dynamic natural system.

It is now recognized that, despite their size and biodiversity, the world's oceans cannot provide an inexhaustible supply of goods and services for human use. In addition, these systems have inherent non-monetary value that must be respected. There is ample evidence that variability in the physical environment and lower trophic levels, variability in the abundance of high-level predators, and human activities can have significant and long-lasting effects. Marine ecosystems are complicated assemblages of organisms ranging in size from the smallest bacteria and viruses to large fish and marine mammals. As such, ecosystems are examples of complex systems (Levin 1999) which are difficult to measure over short periods of time because of the wide range of scales that determine the state of the ecosystem. The structure and functioning of marine ecosystems reflects the myriad of interactions between the physical, chemical and biological components over evolutionary history and at ecological, spatial and temporal scales ranging from centimetres to hundreds of kilometres and seconds to many decades (NRC 2002). Many of these interactions can have non-linear or threshold effects such that small changes in one part of the system can have large effects elsewhere making prediction difficult and uncertain. Human impacts on marine ecosystems in the last century also mean that in most cases we do not have a clear picture of what the unexploited ecosystem looked like (e.g. Jackson et al. 2001)

Given this complexity, understanding comes slowly from a variety of research approaches, including short-term process studies (e.g. studying the effects of temperature and food availability on growth or reproduction) and long-term monitoring studies (e.g., ocean temperature, current patterns, species abundance surveys at various trophic levels). Long-term ecological studies are predicated on the straightforward assertion that processes such as succession, climate change, and other habitat disturbances are long-term processes and must be studied as such. Indeed there are many examples in the scientific literature where interpretations from short-term ecological studies are at odds with similar data sets collected over much longer time scales (e.g., marine assemblage responses to El Niño and NAO [North Atlantic Oscillation]). Clearly both short-term and long-term research is required. Human activities also act at different scales and often selectively impact upper trophic levels (e.g. Atlantic cod) in the case of offshore waters or through eutrophication in coastal areas. These impacts may have cascading effects on lower trophic levels and broader and more longer-lasting effects than might otherwise have been imagined (Carpenter et al. 1985, NRC 1996).

Thus the ESSIM plan must include a long-term (i.e., multi-decade) perspective. This long-term perspective will be one of the strengths of the plan given that long-term measurements are needed to detect ecosystem change and to make inferences about the causes of those changes. Long-term research and monitoring will be critical to our ability to disentangle the relative influence of human activities and natural variability on ecosystem characteristics. Developing a basic understanding of the processes structuring the Eastern Scotian Shelf ecosystem and supporting the diverse array of marine life will benefit greatly from a broad interdisciplinary approach. Scientists from many disciplines, and managers, should collaborate from the outset, jointly developing research ideas and an interdisciplinary (as opposed to simply multidisciplinary) approach to data collection, analysis, modeling and the development of management tools. There is continuing intense public debate surrounding the relative impacts of human activities (e.g., such as fishing) and natural environmental variability on the dynamics of single species, groups of species or broader communities. We simply cannot hope to understand, resolve or mitigate these issues without a long-term commitment to physical, chemical and biological research and their integration. To maximize gains from short-term studies, modeling of recent (i.e. the last few decades for which data exist) ecological conditions are encouraged and have in some cases been carried out. Model results validated with data from short-term research will provide insights on recent ecosystem changes and will aid in making decisions on long-term monitoring strategies.

Conceptual models of the structure and functioning of the Eastern Scotian Shelf would provide a framework within which to identify those components of the system that are of particular concern to society and to guide the planning of research. A strong conceptual foundation is also needed to buffer long-term goals of the research from the short-term demands of the day. The framework must be specific enough to guide the first years of the plan, but general and flexible enough to remain relevant over the longer term and to respond to new, and yet unforeseen, management issues and to accommodate increased understanding of the ecosystem and its components. No one can hope to anticipate all the various taxa, species or issues that will emerge as critical to the development of public policy over the coming decades.

2.2 MANAGEMENT CONSIDERATIONS AND HUMAN IMPACTS

An array of human use objectives for the Eastern Scotian Shelf has been identified and discussed within the context of the ESSIM initiative. These range from harvesting of renewable living resources to oil and gas development and other non-renewable uses. The top level ecosystem based management objectives in Canada are (DFO, 2001):

i. to conserve enough components (ecosystem, species, populations, etc.) so as to maintain the natural resilience of the ecosystem, thus implying the need to maintain communities, species and population within bounds of natural variability;

ii. to conserve each component of the ecosystem so that it can play its historic role in the foodweb. This implies maintaining primary production, trophic structure, and mean generation times within the bounds of natural variability; and

iii. to conserve the physical and chemical properties of the ecosystem.

A set of high-level decision rules or guiding principles is being developed to govern the implementation and management of these objectives. These guiding principles will govern the management decision-making process to ensure that the high-level ecosystem objectives are not compromised by management of human activities. It is inevitable that some human uses of ecosystem components and the supporting ecosystem must be controlled, limited, or prohibited to meet ecosystem conservation objectives. In cases where agreed ecosystem and human use objectives are incompatible, management decision-making should be informed by the limits required to meet the affected ecosystem objective(s). Guiding principles are also essential in cases where multiple ocean use may exceed the ecosystem limits. In such cases preference may be given to the use(s) that have the smallest ecological footprint(s).

For example, one guiding principle is that the harvesting of living resources must be within the carrying capacity of the harvested resources. This directly addresses objective ii.) above by ensuring the conservation of harvested ecosystem components. We must also consider the indirect effects of such management decisions: e.g. the impacts of fisheries or other human activities on other non-targeted ecosystem elements. Such action must not significantly alter the structure and functioning of the ecosystem to ensure that objectives i.) and ii.) can be met. In the case of extraction and use of non-living resources the principle would be that these are undertaken in an environmentally sound manner so that ecosystem structure and functions are not significantly altered and the ecological footprint is minimized. In the case of contaminants introduced to the environment these would be regulated to be within the assimilative capacity of the ocean as measured by the best available environmental quality indicators. The specific nature of these guiding principles will require significant consultation and conversation to ensure that they promote the attainment of the overall ecosystem management objectives.

There is a wide range of impacts from human activities on the Eastern Scotian Shelf that can be broadly categorized as fishing, oil and gas, defence, transportation, telecommunication infrastructure, activities affecting long-term climate change and the long-range transport of contaminants. Although the latter two categories are beyond the reach of the regional management plan, they are included because of their potential influence on the Scotian Shelf ecosystem. The influence of these external factors can have a variety of impacts that operate on a range of spatial and temporal scales. Other influences, not specifically considered, are accidental impacts or activities occurring in the coastal environment (<30 m depth) and land-based activities.

The emphasis on scales of impacts stems from the premise that ecosystem components or processes most directly affected by human activities can be predicted to some degree by the extent to which their scales overlap. For example, an activity with short-term, localized benthic impacts will be significant to an unusual benthic community only if it occurs at the same time and in the same place. As zones of influence expand in either time or space, so does the list of potentially affected ecosystem components or processes. In addition, the importance of scale is being increasingly reflected in environmental management plans as environmental planners accept that management objectives have to be nested both spatially and temporally to be viable.

Management of human activities in marine ecosystems occurs against a dynamic biophysical backdrop as outlined above. Our understanding of how the ecosystem on the Scotian Shelf changes and how these changes manifest themselves within the system remains rudimentary. However, we are aware that there are changes that occur over which humans have no control and which have profound impacts on the structure and functioning of the system in which we carry out our activities. Although we have no control over such external factors we must know when they occur (or better yet when they are about to occur) so that our management actions can be adapted to the new conditions. We have seen, for example, that changes in the properties of water masses transported into the area can result in large and long-lasting changes in temperature over large areas of the Shelf and that these in turn have profound impacts on composition and productivity of an array of marine species (DFO, 2003). Such changes must be taken into account in the management of human activities. Not responding to such changes, by adjusting our expectations, is unrealistic and potentially harmful to the system itself.

3.0 PHYSICAL AND OCEANOGRAPHIC SETTING

The Scotian Shelf is a broad (~200 km, 90 m average depth) continental shelf made up of a number of shallow offshore banks and inner basins. The Eastern Scotian Shelf (ESS, Figure 1), which extends from the Laurentian Channel in the northeast to a line from Halifax south to the shelf break in the southwest, has an area of approximately 100,000 km^2.

3.1 CURRENTS AND WATER MASSES

The nature of the physical environment of the Scotian Shelf is governed by two primary factors: its location, near the meeting place of major currents of the Northwest Atlantic; and its complex topography. The major currents that influence conditions on the Scotian Shelf (Figure 2, 3) are a Shelf current, which brings cool fresh water primarily from the Gulf of St. Lawrence, the Labrador Current which brings cold fresh water from the north along the edge of the shelf, and the Gulf Stream, which brings warm salty water from the south. The Gulf Stream does not contact the Scotian Shelf directly. However, Gulf Stream water mixes with Labrador Current water over the continental slope so that the water along the shelf edge (Slope Water) is cooler and fresher in the northeast and warmer and saltier in the southwest. The shelf-bottom topography consists of a series of submarine banks and cross-shelf channels along the outer shelf and basins and troughs along the central shelf which limit and guide the near-bottom flow.

The distribution of the source waters, with cool fresh water coming from the north and east and warm salty water coming from the south and west, result in the temperature and salinity generally increasing from the coast to the slope region. In addition, the predominance of flow from northeast to southwest means that temperature and salinity generally increase towards the southwest, with exceptions resulting from local circulation and mixing features.

The eastern end of the Scotian Shelf consists mostly of cold fresh water from the Gulf of St. Lawrence and the Newfoundland Shelf. Mixing with the warmer saltier slope water is limited by the shallow depths of Banquereau Bank, and as a result, the water tends to be cold, especially at depth. The upper 50 m warms in the summer. The dominant oceanographic feature of the eastern Scotian Shelf is the strong south-westerly flow of the Nova Scotia Current, centered between the 100 and 150 m isobaths on the inner shelf. Current speeds are typically 5-30 km per day and vary seasonally, generally stronger in the winter. There is also a subsurface extension of the Labrador Current along the outer shelf edge of the eastern shelf.

The structure of water properties on the central shelf is complicated by the wide channel that connects the Emerald and Lahave Basins to the shelf edge (Figure 1). This channel is a pathway for the warm salty slope water to move into the basins, where it dominates the deep (>100 m) water properties. At shallow depths, the water consists mostly of outflow from the Gulf of St. Lawrence. During the spring, as the near-surface waters warm, the vertical structure consists of three layers: 1) the near-surface, warm, relatively fresh layer, 2) the underlying cold, saltier layer, commonly called the Cold Intermediate Layer and 3) the warm, salty deep layer (Figure 4). A number of processes such as wind and internal tides contribute to mixing these layers. The proportions of the different water masses vary horizontally, vertically, and temporally. As a result of the on-shelf transport of slope water, the waters of Emerald and Western Basins are generally warmer than those of the banks to the northeast.

The hydrographic properties of the Nova Scotia Current are modified on the central shelf by mixing with the slope water. However, its integrity is preserved in the near-shore as it moves to the southwest. The waters farther offshore are also transported southwestwards towards the banks of the western shelf. An additional feature of the western shelf is its proximity to the tidally dominated Gulf of Maine. The increased levels of tidal mixing towards the southwest reduce the vertical gradients in temperature and salinity, especially in the deeper half of the water column. Off southwestern Nova Scotia, the water is mixed from the surface to the bottom at all times of the year.

Overall there is transport of water and organisms from the northeast towards the southwest. This transport is strongest in winter and weakest in summer. This flow is modified locally by the banks and basins, particularly on the central shelf where significant amounts of slope water enter. In addition, other processes such as tides, wind-driven flows and waves of all types generate variability that can exceed the average currents.

The circulation and the differences in source waters account for the dramatic contrasts in bottom temperature, salinity, and vertical structure between the eastern and central shelf. In addition, events in one region do not always occur in the other. For example, the gradual cooling of the bottom waters of the eastern shelf from the mid-1980s through the 1990s was not seen in the central and western regions, and the episodic cooling of the bottom waters in Emerald Basin in 1998 was not observed on the eastern shelf. These different source waters are driven by different components of the large scale atmosphere-ocean system. The eastern Scotian Shelf responds to the conditions in the Gulf of St. Lawrence and the Newfoundland Shelf, which are thought to reflect processes at more northerly latitudes. The deep basins on the central shelf are directly connected to the slope water, where the water properties are determined by interactions between the Labrador Slope Water Current and Gulf Stream. This response to different forcings leads to variations in the temperature, salinity and currents of the Scotian Shelf on many time scales from interannual to decadal.

The temperature, salinity and movement of the waters of the ocean have profound impacts on the distribution, growth and survival of marine organisms. Each organism has a particular range of temperature and salinity which is optimal for its success. Water transports their food and oxygen, removes their wastes and also conveys the less active organisms from place to place. These same currents also distribute human wastes (including municipal, agricultural and industrial wastes) around the marine environment. Knowledge of the physical environment is therefore crucial to the goals of integrated management.

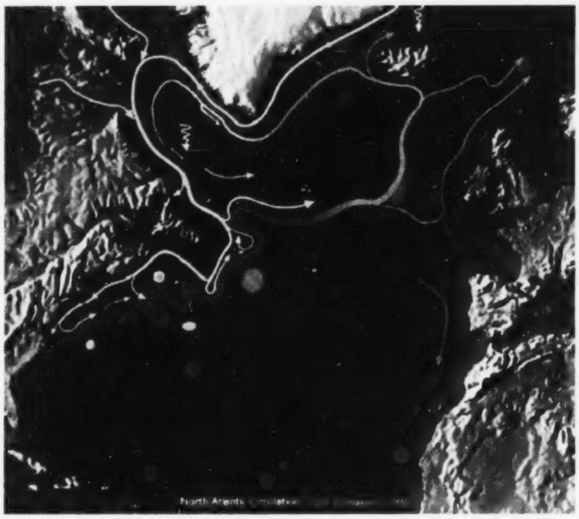


Figure 2: Surface circulation of the North Atlantic. The red arrows indicate warmer, more saline waters and the blue arrows indicate cooler, fresher waters. (Prepared by I. Yashayaev, in Breeze et al. 2002.)

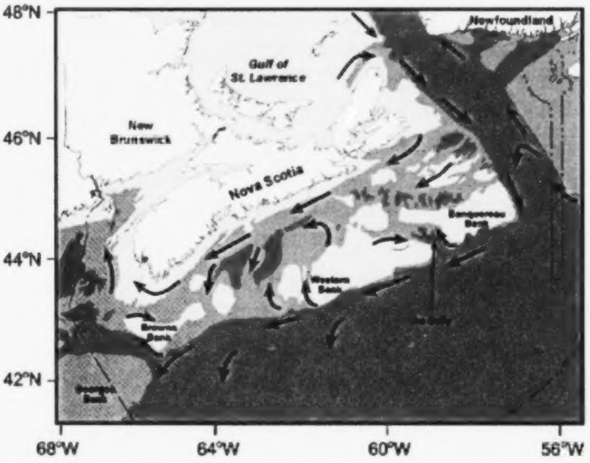


Figure 3: Detailed surface circulation on the Scotian Shelf. (Provided by C. Hannah, in Breeze et al. 2002.)

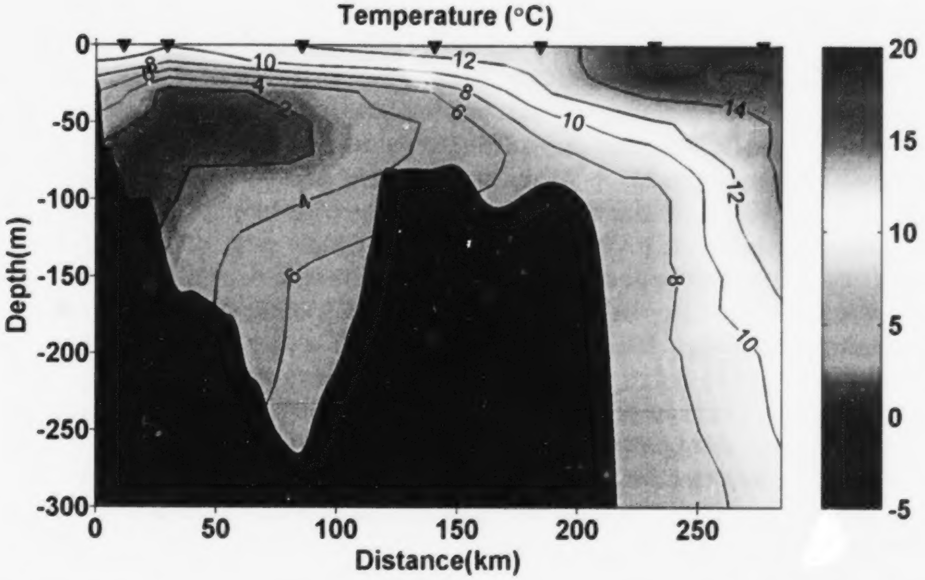


Figure 4. Vertical section of temperature in June 1998 along a line extending from Halifax toward the edge of the shelf. (Prepared by Victor Soukhovtsev.)

3.2 THE SEABED

The basic morphology of the Scotian Shelf is the result of long periods of erosion of the ancient bedrock (King 1980). The shelf can be divided into an inner, middle, and outer shelf, each with its own characteristics (King and MacLean 1976). The inner portion of the shelf, from the Nova Scotia coast (to about 25 kilometres offshore) is an extension of the coastal bedrock with generally rough topography. Sydney Bight is a flat, wide portion of the inner shelf (Figure 1). The middle shelf has broad, deep basins in the central and western portions of the Scotian Shelf, while in the east; the middle shelf is an area of complex topography, with many small to medium-sized banks and small basins ("holes"). This complex topography likely resulted from repeated glaciations of the ESS (Sankerelli and Fader 1999), which differs from the rest of the shelf in this regard: glaciations did not significantly modify the underlying shape of the seabed in other areas of the shelf.

The outer shelf, the portion of the Scotian Shelf farthest from the coast, is a series of relatively broad, flat and shallow banks. Sable Island is an exposed portion of Sable Island Bank and a unique feature of the outer shelf. It supports breeding populations of seals and seabirds, as well as terrestrial plants and animals. On the outer shelf, at about 200 metres in depth (the "shelf break"), the ocean bottom begins to slope more steeply to a depth of about 2000 metres (the continental slope). From about 2000 metres to 5000 metres the slope becomes more gradual (the continental rise). Several large submarine canyons indent the outer shelf, slope, and rise, and some smaller valleys also cross the slope and rise (Piper et al. 1985). The Scotian Shelf is bounded on the east by the Laurentian Channel, a relatively deep channel formed by the outflow from the glacial St. Lawrence River and Gulf of St. Lawrence.

The existing large scale patterns in the distribution of surficial sediments largely reflect the last glaciation and the subsequent rise in sea level that started approximately 10,000 years ago (King and Fader 1986). The surficial sediments of the large outer banks tend to be well-sorted sands and gravel (gravel includes pebbles, cobbles and boulders). The bottoms and sides of the basins tend to be finer sediments (silts and clays, with sand occasionally mixed in). The Scotian Slope has both sandy and gravely sediments and areas where debris and fine sediments have been carried down the slope. There are exposed bedrock outcrops in some submarine canyons and some areas along the Laurentian Channel. More details on the surficial sediments of the eastern Scotian Shelf and Slope can be found in publications of the Geological Survey of Canada (e.g., King 1970, MacLean and King 1971, MacLean et al. 1977, Fader et al. 1982, Fader and Strang 2002, and Piper and Campbell 2002).

Recent technologies (side scan sonar etc) have revealed the presence of geological structures such as small channels and boulder debris fields that may play important roles in the function and structure of ecosystems, e.g. providing refuge, unique niches. The import of these observations have already had significant impact on the harvest of scallops by reducing search time and thereby increasing catch per unit of effort. It also reduces the amount of time fishing gear is on contact with the bottom and reduces collateral impacts. Further implications of these small scale features with regard to micro-habitats and their significance for the ecosystem structure and function will no doubt contribute to our understanding of how these ecosystems function as the technology becomes more widely available and more generally applied.

4.0 MAJOR ECOSYSTEM COMPONENTS

4.1 PHYTOPLANKTON

Phytoplankton constitutes the base of the marine foodweb and consequently their production sets an upper limit on the production of all higher trophic levels. In fact, the world's great coastal fisheries are invariably located in regions where primary production is highest (e.g., the Grand Banks and Georges Bank in the Northwest Atlantic). Phytoplankton are distinctive among ocean biota in that they derive their energy and structural materials directly from the environment (i.e. they are autotrophic); all higher trophic levels obtain their nutrition by feeding on other organisms or their wastes (i.e. they are heterotrophic). For this reason the distribution, abundance and production of phytoplankton can be explained largely by the physical and chemical properties of their environment. More specifically, light (for energy) and the availability of dissolved inorganic nutrients (for structural materials) are the main limiting factors for phytoplankton growth. Biological "top-down" regulation of phytoplankton abundance and growth (i.e., grazing by zooplankton and invertebrate larvae) can also be important under certain circumstances, but physical and chemical "bottom-up" control is thought to be the major determinant, especially in temperate coastal waters such as the Scotian Shelf.

The complex nature of the physical oceanographic features (proximity to major boundary currents, watermass transport, mixing) of the Scotian Shelf determines, to a great extent, the patterns of abundance of phytoplankton. High-frequency spatial (kilometres) and temporal (days) variability in phytoplankton biomass is a common feature of the Scotian Shelf. Superimposed on this is a distinctive seasonal cycle of growth characterized by a conspicuous and wide-spread spring biomass peak (the spring "bloom"), and a more diffuse fall bloom.

Contemporary thinking suggests that the annual growth cycle may be as important in linking phytoplankton to production at higher trophic levels as the bulk (annual) primary production. For example, recent analysis of the phytoplankton and zooplankton growth cycles on the Scotian Shelf has shown that strong year-classes of haddock (1981, 1999) coincided with years when the onset of the spring phytoplankton bloom and reproduction of zooplankton were notably earlier than in years when recruitment was average (Platt et al., 2003; Head et al. 2005).

Since phytoplankton derive their energy from the sun, their growth is dependent on the amount of light they receive. On the seasonal scale, light availability is determined by the annual solar cycle (minimum in winter and maximum in summer), but on shorter time-scales it is determined by the position of the phytoplankton in the water-column; shallower depths receive more light, because light intensity decreases exponentially with depth. Mixing of the surface of the ocean plays a major role in determining the position of phytoplankton in the water-column and their access to light. Optimum conditions for phytoplankton growth, with regards to light, occur under stratified upper ocean conditions, which may be induced either by surface heating or freshwater input. Theory suggests that light is the primary determinant of the *timing* of the spring phytoplankton bloom in north temperate waters. On the Scotian Shelf, therefore, early spring mixing (or stratification) would be a critical physical property to monitor, since it likely determines the timing of the spring bloom. Recent analyses have shown that the timing of the spring bloom on the shelf (based on Continuous Plankton Recorder [1] and satellite data) is earlier now than it was in the 1960s and 1970s (Sameoto 2004). This has been attributed in part to the decrease in late winter storminess in recent years; decreased storminess could translate to less intense mixing and earlier stratification, during the spring, when the bloom occurs. There is also evidence of a general increase in stratification intensity over the past few decades on the shelf, attributable primarily to decreased surface salinities associated with increased freshwater input.

While less mixing and increased stratification provides a more favourable light environment, these same physical conditions diminish the supply of deep-water nutrients for phytoplankton, the other major environmental factor limiting their growth and production. Theory suggests that nutrient levels determine the *magnitude* and *duration* of phytoplankton blooms. Therefore nutrient levels and the physical processes that make nutrients available for phytoplankton in temperate coastal waters (e.g. wintertime mixing, advection, upwelling, frontal exchange, turbulent/diffusive vertical mixing during summer stratified conditions) are important properties to monitor, and might enable us to estimate or forecast the total quantity of phytoplankton produced. In contrast to spring, when light levels are low and determine the timing of the bloom, nutrients may be more important in fall bloom timing. In the fall, light levels are still relatively high but surface nutrients are depleted. Increased (moderate) fall mixing will recharge the surface waters with nutrients, while still providing enough light and a bloom will be initiated. Its duration; however, will most likely be limited by light availability, that is, determined by how quickly increased storminess (and mixing) will dissipate the bloom or mix the phytoplankton to depths to which they do not receive enough light to sustain growth.

Decadal trends in the magnitude and duration of the spring bloom on the Scotian Shelf indicate, that blooms start earlier now than they did in the 1960s and 1970s, and that spring blooms are now more intense and last longer. This would imply that winter nutrient stores are higher now than decades ago (Sameoto 2004). This is not, however, consistent with the observation of less storminess in recent years, which should lead to less winter deep mixing and should result in lower surface nutrients. As deep-water nutrient levels vary with water mass, a major change in the water masses influencing the Shelf could explain changes in nutrient levels. For example, Scotian Slope waters are characterized by higher nutrients and lower oxygen content than Labrador Current waters, and Gulf of St. Lawrence waters have higher silicate levels than do slope and Labrador waters. Clearly, the influence of physics (modifying both light and nutrient conditions) on phytoplankton growth is a double-edged sword and a variety of often opposing processes influence phytoplankton dynamics. In addition to the influence of physical processes on the production of phytoplankton, Physical processes also have a role in their fate; through mixing (dispersion) and advection into and out of a particular region. In addition to these processes, the dynamics (timing and magnitude) of the principal phytoplankton grazers (zooplankton) will determine the extent to which phytoplankton production is transferred to the pelagic food chain or goes directly, as phyto-detritus, to the benthos.

---

[1] The CPR is towed by commercial ships at a depth of about 7m and catches plankton between two strips of silk mesh, which are wound on to a drum and preserved for subsequent analysis.

Phytoplankton community structure on the Scotian Shelf is not well known in detail, although general features common to all north temperate coastal waters, are understood. Photosynthetic forms range in size from one micron (e.g. cyanobacteria, ultra phytoplankton) to hundreds of microns (diatoms, dinoflagellates). Phytoplankton biomass is dominated by the latter forms. Spring and fall blooms on the shelf are comprised principally of diatoms that decrease in importance in summer and fall when flagellates dominate. Because of the complex mixture of water masses on the Scotian Shelf, arctic, temperate and subtropical forms occur on the shelf at various times. Decadal trends in the larger forms from CPR data analysis indicate that during the cold water periods of the 1960s, the relative proportions, particularly in the spring, of diatoms were much greater than dinoflagellates. In contrast, during the warmer water periods of the 1970s and more recently, diatom dominance has diminished and dinoflagellates have become more important particularly in the fall (www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html). The link between these structural changes and changes in bloom dynamics is under investigation. The consequences of structural changes in phytoplankton community to higher trophic levels is not yet known, although some research has suggested that first-feeding larvae of certain fish species survive better on a diet of diatoms than dinoflagellates. Zooplankton, the principal grazers of phytoplankton, also show feeding preferences for some phytoplankton forms over others (Head and Harris 1994).

4.2 ZOOPLANKTON

Zooplankton are divided operationally into three main categories on the basis of size. The microzooplankton includes single-celled protozoa of ca. 0.005-0.05 mm and larval stages of crustacean copepods of up to 0.2 mm in length. The protozoa have important roles in the re-cycling of nutrients, and as food sources for larger zooplankton. The mesozooplankton (0.2-2 mm in length) are dominated by copepods, and these provide the main link between the phytoplankton and higher trophic levels, although most are omnivorous, feeding on phytoplankton, microzooplankton and small detrital particles. The macrozooplankton are >2mm in length and include actively swimming euphausiids and cheatognaths, and more passive forms such as salps and jellyfish. Euphausiids are omnivorous and along with the copepods are an important food source for higher trophic levels. Cheatognaths are ambush predators that feed on copepods. Salps are grazers that can feed on the very smallest phytoplankton species, while jellyfish are generally predators feeding on copepods, euphausiids and larval fish.

On the Scotian Shelf the mesozooplankton communities are consumed directly by larval and juvenile groundfish, juvenile and adult pelagic fish, baleen whales and seabirds. The shelf community is characterised by relatively high mesozooplankton biomass (1-6 g dry wt. m^{-2}) (Head and Harris, 2004), relatively low diversity, and most species exhibit seasonal cycles of abundance. Copepods, small primitive shrimp-like creatures, generally account for >80% of the biomass and abundance of mesozooplankton in the 0-100 m depth range in spring and >70% in fall.

Three species of *Calanus* usually make up > 70 % of the copepod biomass on the Scotian Shelf in spring: *C. finmarchicus*, a North Atlantic species (Figure 5); *C. hyperboreus*, an Arctic deep-water species; and *C. glacialis*, an Arctic shelf species. All three species are mainly herbivorous and share similar life-histories. Individuals begin life as eggs, broadcast into the water column, which develop through 6 naupliar (N1-N6) and 5 copepodite (C1-C5) stages before reaching the final, adult (C6f or C6m) stage. All three species also share the ability to overwinter in a resting non-feeding state, which they do at depths of > 100 m. The term "overwinter" is something of a misnomer, however, in that the retreat to depth starts in May/June and is more-or-less complete by August, while the return to the surface layers occurs in February/March. The three species differ as to which stages can overwinter and in their generation times. *C. finmarchicus* overwinter mainly as C5 pre-adults and populations on the Scotian Shelf go through one or two generations per year. *C. glacialis* overwinter as C4s, C5s or immature adults and probably have a two-year life-cycle. *C. hyperboreus* overwinter as C3s, C4s, C5s or immature adults and likely have a three-year life-cycle.

The requirement for deep water for overwintering means that *Calanus* spp. are not found over most of the shelf for part of the year, although overwintering *Calanus* spp. are present in dense layers near the bottom of the shelf-basins (Sameoto and Herman 1990), where they are heavily preyed upon by fish and, in Roseway Basin, by right whales. High concentrations also accumulate near the bottom of the Laurentian Channel, where *C. hyperboreus* dominates in terms of biomass and *C. finmarchicus*, in terms of numbers (Erica Head, research scientist, Bedford Institute of Oceanography, personal observation). Large numbers of *Calanus* spp. also accumulate at depths of ≥400 m along the shelf break. In the west these populations are dominated by *C. finmarchicus*, while off Banquereau the composition is similar to that found in the Laurentian Channel. Individuals from these deep populations swim up to the near-surface layers in late winter/early spring and are subsequently transported onto the shelf by the circulation. The population overwintering in the Laurentian Channel provides the source for the eastern Scotian Shelf and the cold waters there and in the Nova Scotia Current are dominated by *C. hyperboreus* in spring (Sameoto and Herman 1992). Farther west the *Calanus* populations overwintering in the slope waters and shelf basins also contribute to the shelf community. *C. finmarchicus* is dominant in these warmer waters in spring and early summer (Figure 6; Head et al. 1999). All three species appear at the surface at more-or-less the same time (February/March) but because the Arctic *Calanus* spp. cannot tolerate warm temperatures, they leave the surface layers earlier than *C. finmarchicus* (May *vs.* June/July).

C. finmarchicus has attracted the attention of fisheries biologists because its eggs and nauplii are preferred food items for spring-spawned cod and haddock larvae (Ellertsen et al, 1989). Female *C. finmarchicus* start to lay eggs shortly after the start of the annual spring phytoplankton bloom, which they feed on to fuel reproduction and which generally occurs in March or April (Figure 7;

Head et al 2005). They continue laying for a month or so and since cod and haddock also spawn during this period, there is generally a plentiful supply of food for the early larvae. As the *C. finmarchicus* grow and develop, so do the fish larvae, the latter consuming ever larger stages of the former, until the juvenile groundfish leave the surface layers to settle near the bottom in June or July (Mahon and Nielsen 1987). Over this period *C. finmarchicus* individuals also descend as C5s, entering into their overwintering state. Disruptions in the normal timing of the phytoplankton bloom and *C. finmarchicus* reproductive and developmental cycles may have serious consequences for the survival of pre-settled groundfish and may influence the dynamics of subsequent recruitment.

C. finmarchicus eggs take about 4-6 weeks to develop into a C5 copepodite depending on temperature and food conditions. Over such a period individuals may be transported by the circulation onto or off the shelf, or from one area to another. Overall it has been estimated that > 60 % of the annual net production of *C. finmarchicus* on the shelf is exported to the southwest: a portion being retained along the shelf edge, but most being transported to overwinter in the deep basins of the Gulf of Maine, never to return to the Scotian Shelf (Zakardjian et al. 2003). *C. finmarchicus* that grew up on the Scotian Shelf resurface to seed populations that grow and develop in the Gulf of Maine and on Georges Bank, but individuals of the Arctic *Calanus* species do not, probably because of the higher temperatures.

Calanus spp. may dominate the biomass of the mesozooplankton, but *Oithona* spp. is numerically most abundant. This genus has a ubiquitous distribution and is small so that its naupliar and early copepodite stages are not retained by a 0.2 mm mesh net. Nevertheless, the later stages generally account for > 40 % of the copepods caught. The average weight of those that are retained is only about 1.2 μg per individual, so that *Oithona* spp. only occasionally accounts for > 10 % of the mesozooplankton biomass (Head and Harris, 2004). *Oithona* spp. is thought to eat non-living particulate material, rather than phytoplankton, and thus the annual cycle of abundance is not closely linked to that of the phytoplankton.

Among the variety of other Scotian Shelf copepod species, there are several small species that go through several generations per year, with generation times decreasing as temperatures increase over the summer, and peaks in abundance tending to occur in late summer. Small populations of some of these species remain in the surface layers over the winter. Others lay dormant eggs that sink and lie buried in the surficial sediment over the winter, hatching as spring approaches. Larger copepods are generally longer lived, although, apart from *Calanus* spp., not much is known about their life cycles on the Scotian Shelf.

Many copepods undertake daily vertical migrations: moving towards the surface layers at dusk to feed overnight and descending at dawn to avoid being seen and consumed by visual predators. The extent of these migrations is related to size; small copepods may migrate only 10 m or less, while large copepods may retreat to depths of > 100 m. Migrations are strongest when sub-surface light levels are highest, *i.e.*, in the summer after the spring bloom. For some species, this behaviour means that the later stages are restricted to the shelf basins, while the younger stages may also occur in shallower areas. Vertically migrating warm water ex-patriot species, which do not persist, are also sometimes found in the shelf basins that have inputs of warm slope water (*e.g.*, Emerald Basin).

Euphausiids, or krill, have an important role on the Scotian Shelf (Figure 8). They are omnivorous; the youngest stages feeding on phytoplankton and then small zooplankton as they grow. They are, in turn, eaten by juvenile groundfish and pelagic species, as well as baleen whales. *Meganyctiphanes norvegica* is the dominant species with a generation time of 2-3 years. Adult *M. norvegica* are much larger (up to about 4 cm in length) and are much stronger swimmers than copepods; and they can also avoid the nets commonly used to catch mesozooplankton. *M. norvegica* perform extensive vertical migrations, and by day are found in dense layers in the deep basins and along the shelf-break, at depths of 100-300 m.

Long-term changes in the abundance of certain important members of the mesozooplankton community have been observed in samples collected on a monthly basis by the Continuous Plankton Recorder (CPR) program. Collections were made in the 1960-1975 period and since 1991. CPR data show large inter-annual variations in the average annual abundance of the young stages (1-4) of *Calanus spp.* Over the time series, this category has been somewhat less abundant on the eastern Scotian Shelf since 1991 than it was during the 1960-1975 period (by a factor of about 2). In addition, the seasonal peak in abundance has shifted from June/July to May/June (Sameoto, 2004). The interpretation of these changes is not straightforward. One suggestion is that predation by pelagic species, particularly herring, is now higher; herring are much more abundant on the outer shelf now than it was in the early 1970s (DFO 2003). Another suggestion is that one, or all, of the overwintering populations have decreased in size, perhaps due to changes in environmental conditions at depth. It is possible, however, that abundances have not changed, but that individuals are now distributed differently in the water column, making capture efficiency at the 7 m towing depth lower.

CPR data for the eastern Scotian Shelf also shows that *C. hyperboreus* has increased between the two sampling periods. This change has been accompanied by an increase in the amount of cooler, fresher, more Arctic water on the shelf, which may be providing a habitat more suitable for this Arctic species. For other *Calanus spp. (stages 1-4)*, however, the increase might also reflect either a change in the size of the population overwintering in the Laurentian Channel, or in the depth distribution relative to the CPR's sampling depth.

Although the mesozooplankton community cannot be managed, it is important to recognise that changes can occur and that they can affect higher trophic levels. For example, continued or increased influxes of Arctic water may cause *C. finmarchicus* to be increasingly replaced by *C. hyperboreus*. Using stored energy reserves *C. hyperboreus* reproduces in December/January, so that it cannot replace *C. finmarchicus* as a food source for larval groundfish hatching in early spring. Increased influxes from the slope waters to the south of the shelf might favour dominance by *C. finmarchicus*, but if accompanied by increased temperatures there might also be changes in the timing of reproduction and entry into the over-wintering state. Changes in temperature influence not only the distribution of species associated with particular water masses, but also growth and development rates, generation times and productivity of all species. Ongoing DFO monitoring programmes will enable us to understand these processes and interactions more completely and may allow us to develop a predictive capacity for future climate change scenarios.

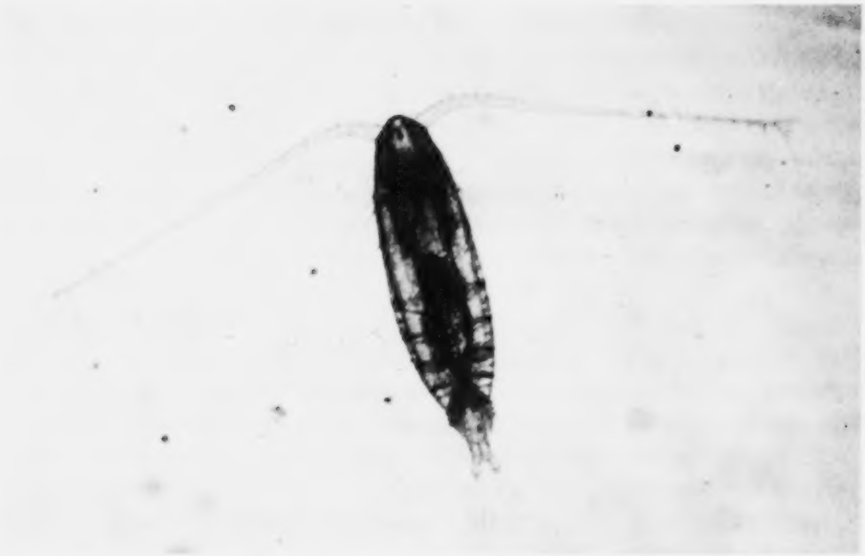


Figure 5. An adult copepod, a *Calanus finmarchicus* female, *about* 2.9mm in length.

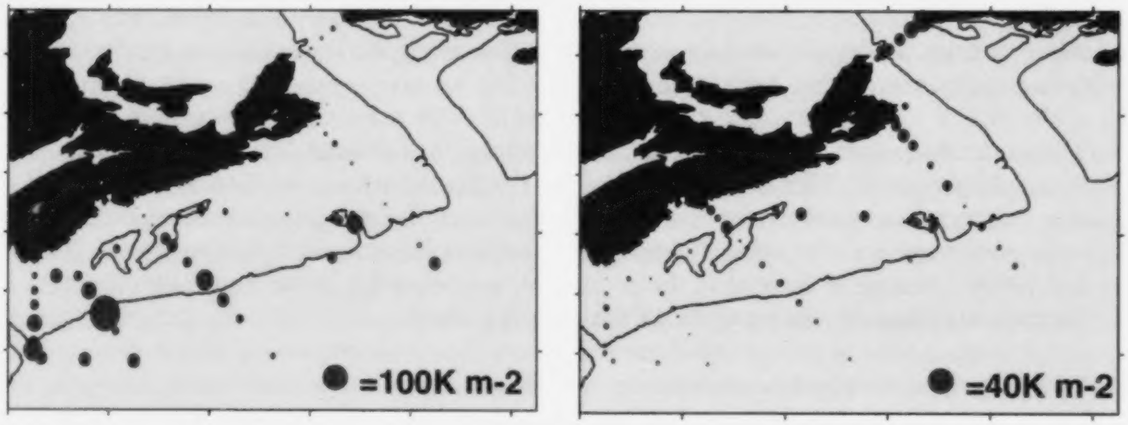


Figure 6. Distribution of *Calanus finmarchicus* (left) and *C. hyperboreus* (right) in the 0-100 m depth range, April 1998.

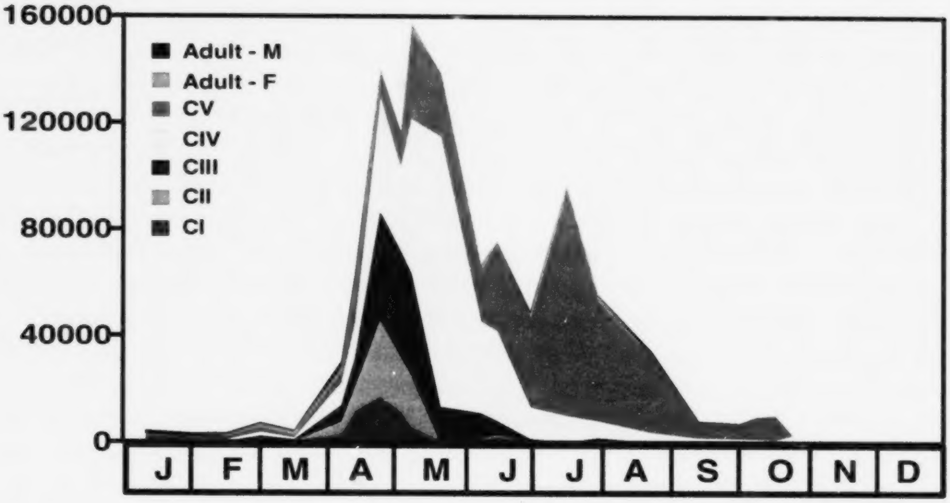


Figure 7. Abundance and copepodite stage distribution of *Calanus finmarchicus* in the 0-150m depth range at station HL2. Until June, most individuals are in the 0-100m depth range; thereafter most are below 100m.

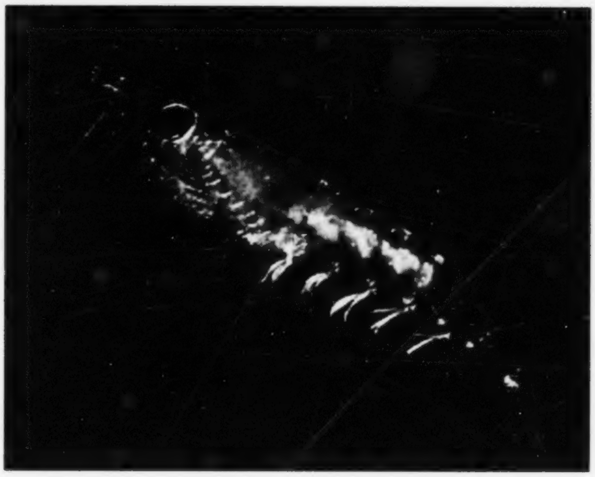


Figure 8. An adult euphausiid, *Meganytiphanes norvegica, about* 3 cm in length.

4.3 BENTHOS

The physical attributes of the seabed are important determinants of habitat and thus the distribution of faunal communities. These attributes are both small scale (millimetres) and large scale (tens to hundreds of kilometres) and include topography (macro relief), roughness (micro relief), grain size and shape, lithology (rock composition), the local variability or patchiness in the bedforms, and the sediment distribution (Fader et al. 1998). Most of these attributes change very slowly – over centuries or millennia. Others, such as the movement of certain bedforms (e.g., sandwaves and ridges), may change over the course of hours or days.

The physiography influences the distribution of benthic communities on both small and large scales. Bedrock outcrops, ledges, and boulders provide shelter from currents and predation for some species, while providing opportunities for filter feeding species to extend themselves above the surrounding seafloor and into currents that carry the planktonic organisms and organic debris on which they feed. The physiography also influences other aspects of habitat, such as current patterns and water column properties. For example, topography influences the flow of currents along the shelf edge, and affects the rates of tidally-induced mixing. The current patterns in turn influence patterns of surficial sediment distribution.

There is ongoing movement of surficial sediments through storms, tides, and bottom currents, and through the activities of benthic fauna. Fauna such as polychaete worms and sand dollars rework surficial sediments. Shell fragments make up a large component of the surficial sediments in some areas of the shelf. Human activities can influence the distribution of surficial sediments, either through direct physical disturbance or through the suspension of sediments in the water column and their subsequent settlement. The distribution of surficial sediments is an important habitat determinant that affects the distribution of benthic faunal communities. The well-sorted, sandy sediments in the shallow portions of Sable Island Bank are frequently moved due to waves caused by storms; and the animals found there – such as sand dollars – are adapted to life in a constantly changing environment. The fine silts and clays found on the bottom of Scotian Shelf basins support a diverse infauna. Glacial erratics and bedrock outcrops host fauna that prefer hard surfaces for attachment, such as sponges and bryozoans.

Given the importance of surficial sediments and their dynamics to the distribution and abundance of benthic fauna, there is a significant effort underway to develop a classification system for benthic habitats on the Scotian Shelf. Potential habitat classification schemes are being investigated, and work has been undertaken to map critical features of the bottom habitat (e.g. sediment grain size, bottom temperature, dissolved oxygen, food supply to the benthos etc). A model is being developed to integrate all this information so that it can be used to classify the benthic communities of the Scotian Shelf, and then to develop guidelines and best practices, for human activities that occur in these areas, to ensure their long-term conservation and integrity. The classification scheme presently being investigated is based on the balance between the frequency and intensity of natural habitat disturbance and the productivity of that habitat. This model was originally proposed by Southwood (1988). Its proposition is that the life history characteristics of benthic organisms found on the ocean bottom, are to some extent, determined by (or selected by) the frequency and intensity of habitat disturbance, and the relative amounts of energy available and required for maintenance versus reproduction. The theory suggests that long-lived, slow growing, and slowly reproducing species would be more likely to occur in habitats that are stable and where food availability is relatively low. Fast-growing, fecund, species are more likely to occur in areas that are subjected to more frequent natural disturbance and where food availability is relatively high. Areas of low disturbance and low food availability, containing slow-growing, slow-reproducing species would be more susceptible (i.e., slower or less likely to recover) to human disturbance, than areas of high disturbance and high food availability that contain fast-growing, fast-reproducing species that are frequently disturbed.

This classification model will be applied to the bottom habitat of the Scotian Shelf using a number of physical parameters (mainly grain size and current speed as well as their varibilities) to determine relative disturbance indices for each location. Estimates of the amount of carbon reaching the bottom (estimated from chlorophyll *a* distributions and the stratification index), at each of these locations will provide the concurrent productivity, or food availability index.

Classification and ground-truthing of the biota will determine the usefulness of the classification scheme.

4.4 FISH AND INVERTEBRATES

The exploitation of fish and invertebrates is the human activity that has the longest history and the greatest impact on the Scotian Shelf ecosystems. Regulation and management of these fisheries has required a significant annual investment of money and effort by Canada. Until very recently each of the individual fisheries were managed in relative isolation from each other and there was little or no consideration given to impacts on physical environment, or on the broader ecological effects of these fisheries. There has been growing recognition that fisheries cannot be managed in isolation of each other or independent of their impacts on the broader ecosystem. The establishment of ecosystem based conservation objectives is a first step in establishing an ecosystem approach to fisheries management.

A wide array of fisheries either were, or are, operating on the Scotian Shelf as a whole. They pursue a broad range of target species including groundfish (cod, haddock, pollock, etc), small pelagic species (mackerel and herring), a wide range of invertebrates (lobsters, crab, clams, scallops), and large pelagic species (sharks and tunas). A wide variety of capture gears and technologies are used, including, among others, bottom and mid-water trawls, bottom longlines, gillnets, traps, dredges (both hydraulic and traditional), and pelagic long-lines. Each of these gears has a specific impact on both the physical environment and the particular array of species that they capture both as targets and as bycatch (see section on bycatch below). Managing the operation of these fisheries and recognizing their unique impacts will be a challenge to integrated management.

4.4.1 Demersal and Pelagic Fish

4.4.1.1 Data Availability: Systematic collection of fisheries statistics for the Scotian Shelf goes back to the late 1800s (although there is scattered information available back to the 1500s). Systematic fishery independent trawl surveys of the Scotian Shelf began in 1970, with a significant volume of less synoptic surveys dating back to 1948. Fisheries statistics describe the nominal patterns of fish and invertebrate exploitation, while the results of trawl surveys (survey design and protocols described by Halliday and Koeller, 1980) describe temporal patterns of species composition and diversity, changes in population numbers and biomass, and trends of mean body size both for individual species and for elements of the fish community as a whole.

4.4.1.2 Historical Information: Harvesting the Scotian Shelf by aboriginal peoples started several thousand years ago. Commercial fishing started in the mid-1500s. In 1602, Samuel de Champlain reported meeting a Basque fisherman called Savalet making his 42nd voyage to the Scotian Shelf in 1602 (Innis, 1954) indicating that Savalet would have started fishing there in about 1560, making him one of the first Europeans to fish these waters. By 1709 Nova Scotia was exporting about 10,000 t of cod and 4,000 t of mackerel and herring (Figure 9). By 1806 this had increased to about 40,000 t, and to over 100,000 t by the 1880s. In 1973 total landings of fish from the Scotian Shelf exceeded 750,000 t. In the early 1990s many of the east coast cod fisheries, including that of the eastern Scotian shelf, were closed. For demersal species only the halibut longline fishery and some flatfish fisheries are currently operating on the Eastern Scotian Shelf.

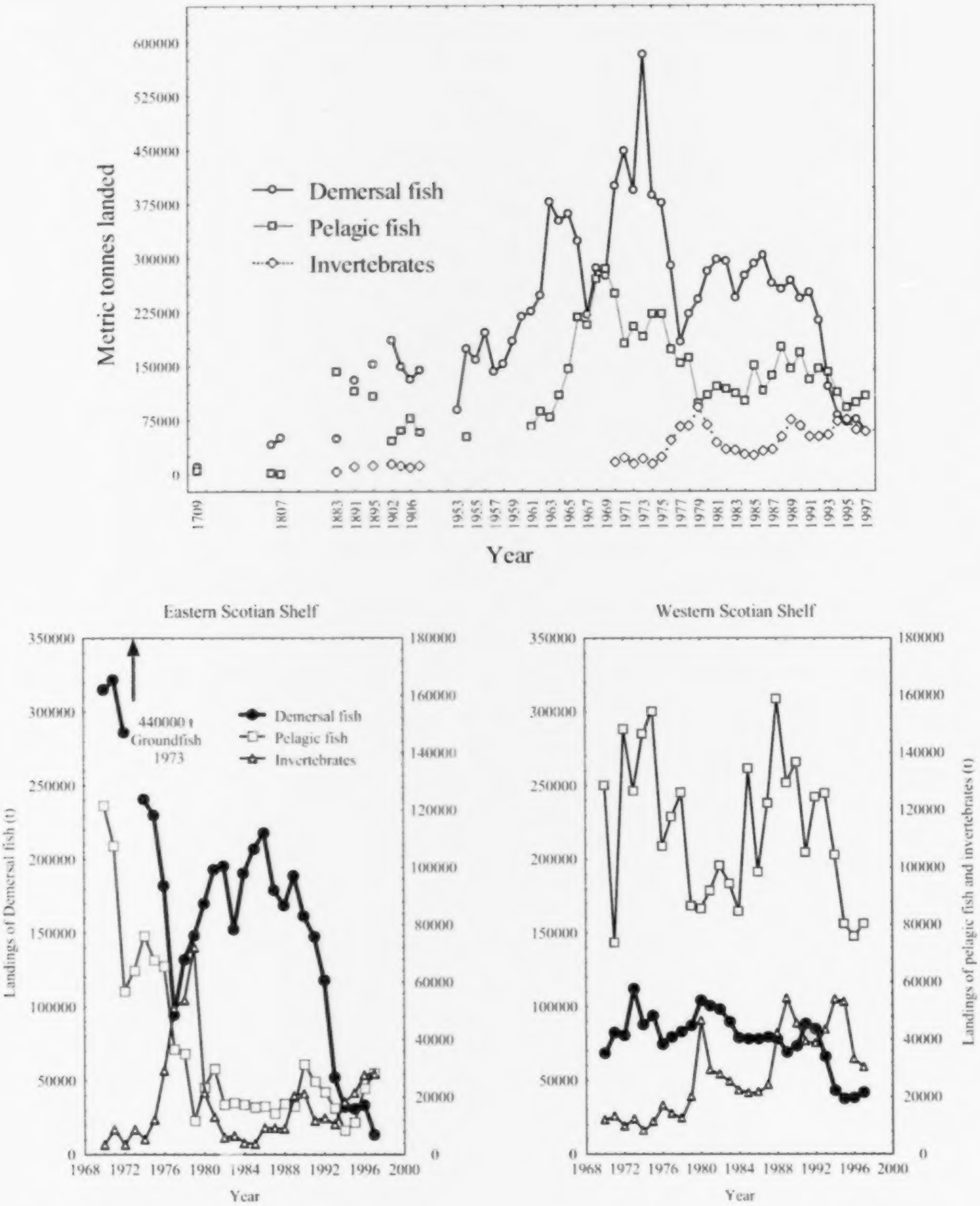


Figure 9. Historical landings of fish and invertebrates from the Scotian Shelf (From, Zwanenburg 2003, Zwanenburg 2000).

4.4.1.3 Recent Fishing Patterns: Total landings of demersal fish (mainly gadids) on the eastern shelf declined from a maximum of 450,000 metric tons (t) in 1973 to less than 15,000 t in 1997 (Figure 9). A moratorium on fishing, especially for cod, was imposed in 1993 and remains in effect. A longline fishery for Atlantic halibut (*Hippoglossus hippoglossus*) is presently the only major demersal fishery operating on the eastern shelf. Landings of pelagic species (mainly Atlantic herring, *Clupea harengus* and Atlantic mackerel, *Scomber scombrus)* declined from about 120,000 t in 1970 to about 20,000 t in 1980s. Landings of herring and mackerel have been higher than during the 1990s but with more interannual variation.. Landings of invertebrates (mainly northern short-fin squid, *Illex illecebrosus*) increased rapidly to, a maximum of about, 75,000 t in 1979. Invertebrate landings then declined substantially to less than 4,000 t in 1985 and then increased to 30,000 t in 1997. This increase is mainly due to increased landings of snowcrab (*Chionoecetes opilio*) and northern shrimp (*Pandalus borealis*). It is noteworthy that both of these invertebrate species prefer cold water and their increased landings coincide with the cooling of the eastern shelf, noted above. They are also both prey for cod.

4.4.1.4 Changes in Fish Biomass: Trawlable demersal biomass is near the lowest observed in 30 years (Figure 10). Biomass declined by 80% from the early 1980s. Declines in target biomass (defined as the biomass of those species actually landed and sold) are evident. Atlantic cod accounted for a long-term average of about 28% of the total biomass; at present cod makes up only a few percent of the total. The recent increase in the prevalence of sandlance (*Ammodytes dubius*) on the eastern shelf is notable, especially relative to the abundance of cod, one of its main predators. The removal of cod biomass is correlated with an increase in sandlance biomass, which then becomes available to other predators (Figure 11, see also Marine Mammals below). The ratio of demersal fish to pelagic fish biomass has also shown a steady decline on the eastern shelf since the early 1980s.

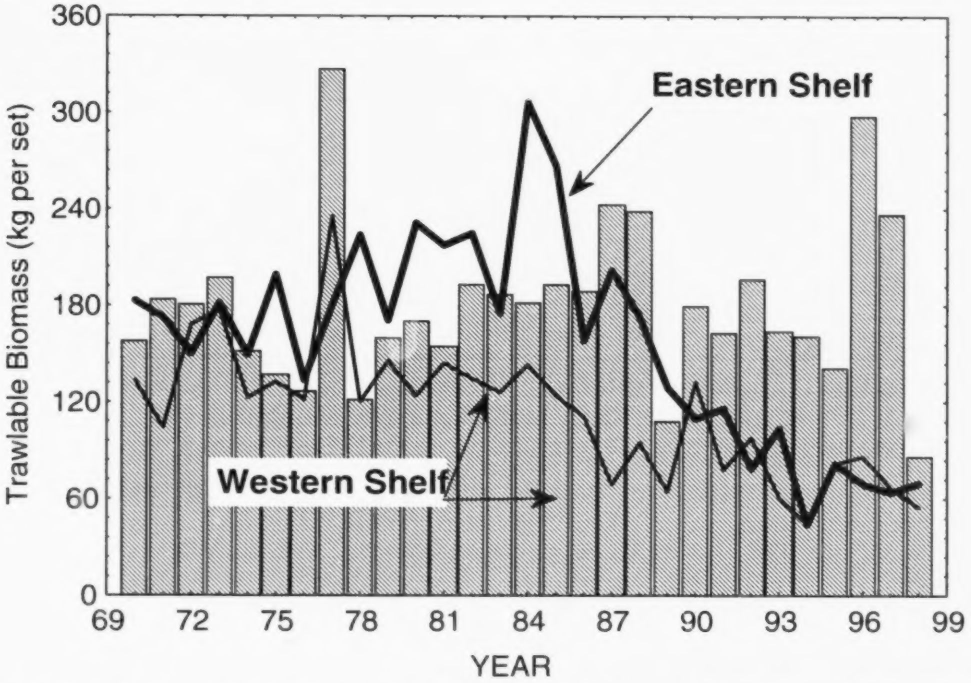


Figure 10. Trends in trawlable biomass for demersal fish species. The heavy line represents the trend for all demersal species on the eastern shelf, while the bars show this trend for the western shelf. The lighter line shows the biomass trend for the western shelf excluding dogfish (*Squalus acanthias*) from Zwanenburg et al. 2002.

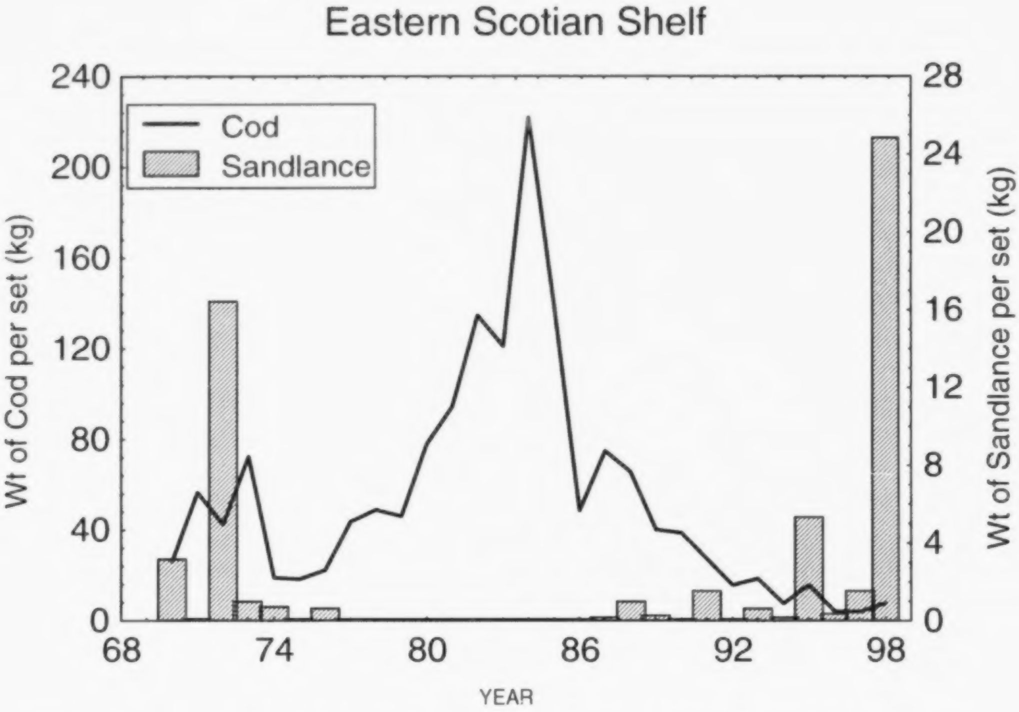


Figure 11. Trends of cod (*Gadus morhua*) and sandlance (*Ammodytes dubius*) biomass on the eastern shelf (From Zwanenburg et al. 2002).

4.4.1.5 Changes in Average Fish Weight: The average size (weight) of a demersal fish (top 60 species combined) declined by 66% between 1970 and 1995. Declines in aggregate mean size are coincident with increasing fishing effort for the period 1977 to 1995. From 1995 to 1998 the trend was toward stable or increasing mean weights in the eastern and western Scotian Shelf (Figure 12). This trend, in increasing mean weights, was coincident with the imposition of a moratorium on fishing for cod on the eastern shelf, and a significant reduction in total allowable catches on the western shelf.

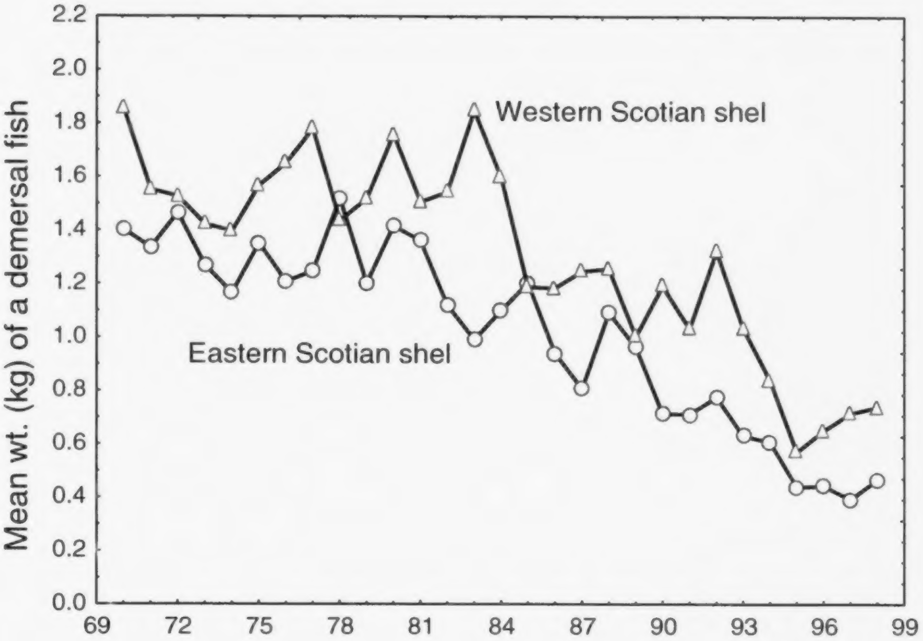


Figure 12. Trends in average weight of demersal fish (all species) since 1970 for the eastern and western portions of the shelf (from Zwanenburg et al. 2002).

4.4.1.6 Changes in Integrated Community Size Frequency (ICSF): The integrated community size frequency (ICSF) was estimated as the density (numbers per hectare) of all fish by size class (without regard to species). The slope of the descending limb of the ICSF (log transformed numbers at length versus length class) is an integrated measure of growth and mortality for the component fish species. The slope was calculated for fish between 35 cm and 85 cm. These sizes represent the linear portion of the descending limb of the ICSF. The trend of the annual ICSF slope estimates (each points represents the slope of the descending limb of the ICSF for that year) shows long-term declines (increased steepness, Figure 13). These increases in steepness of the ICSF indicate long-term reductions in the number of larger fish on both the eastern and western Scotian Shelf. This is consistent with the observed decreases in average weight of fish caught by the surveys.

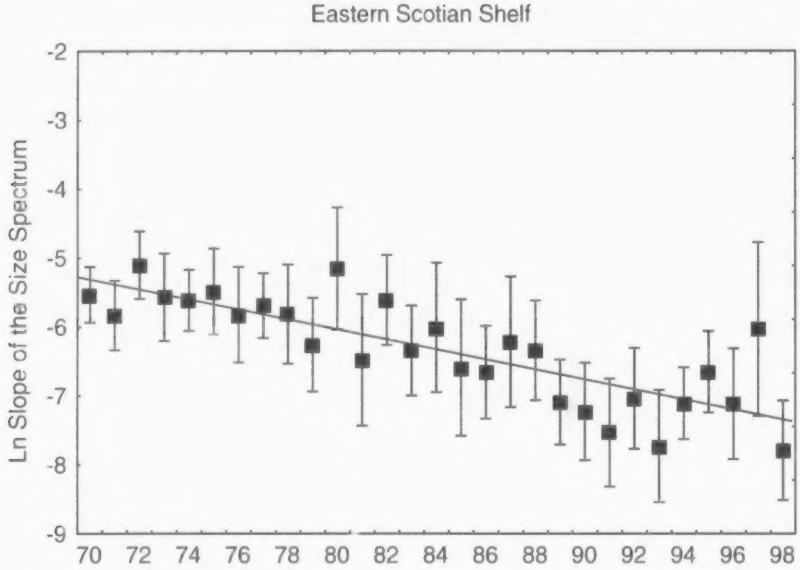


Figure 13. The integrated community size frequency (ICSF) for the eastern and Scotian shelf. Each point represents the average number of demersal fish per hectare caught at length over the 29 survey years (from Zwanenburg 2000).

Reduced numbers of larger fish may have significant impacts on long-term recruitment success. Longhurst (1999) theorised that north-temperate demersal species rely on longevity and large maximum size of spawning females to bridge frequent gaps in recruitment success. Large females ensure a large supply of eggs each year. In years when conditions are not conducive to survival there are sufficient eggs to maintain some reproductive success for the population. In years of high survival rates, these large numbers of eggs provide the basis for the large year-classes that characterize the recruitment dynamics of this and similar species. The observed reduction in number of large fish, and the current small average size of fish, is not conducive to such a strategy. In addition to the absence of large highly fecund cod, Trippel et al. (1997) have shown that the egg viability is lower for smaller, first time spawning cod than for older multi-year spawners. The reduced overall size therefore not only produces fewer eggs but less viable eggs. This combination of effects may seriously impair the populations' ability to sustain or rebuild itself or a fishery.

Cumulative fishing effort was negatively correlated with the slope of the Integrated Community Size Frequency (Figure 14). The reduction in cumulative fishing effort during the early 1990s is correlated with decreases in the steepness of the annual slopes of the ICSF and, therefore, indicates an increase in the overall size of fishes in both portions of the Scotian Shelf.

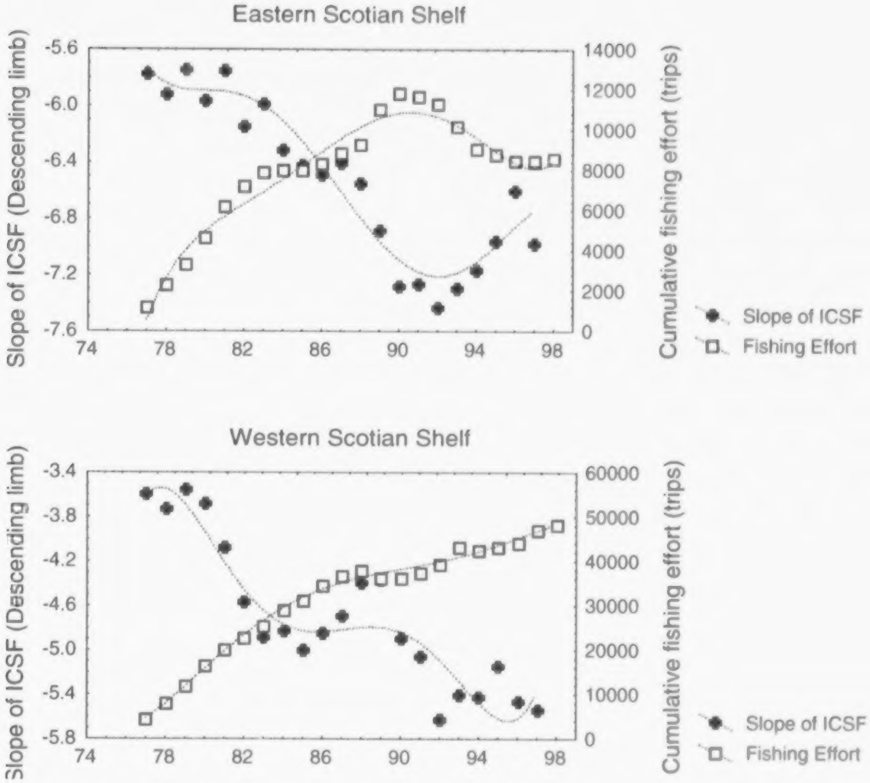


Figure 14. The relationship between cumulative fishing effort and slope of the descending limb of the integrated community size frequency (ICSF) for the two Scotian shelf systems (from Zwanenburg et al. 2002).

4.4.1.7 Changes in Fish and Invertebrate Distribution: Changes in the oceanic environment, such as the cooling events of the mid-1980s to the mid-1990s, had significant impacts on fish and invertebrate distribution. Because each fish species or stock tends to prefer a specific temperature range (Scott, 1982), long-term changes in temperature can lead to expansion or contraction of its distribution range. These are generally most evident near the northern or southern boundaries of the range with warming (cooling) resulting in a northward (southward) shift. Associated with the cooling in the latter half of the 1980s, capelin, a cold water species, began to appear in the north-eastern Scotian Shelf annual summer groundfish surveys (Frank et al., 1996). Through the intervening years, the abundance of capelin gradually increased. These capelin are believed to have come from either the Gulf of St. Lawrence or eastern Newfoundland waters. Initially only adults were caught but over the years, juveniles were found indicating that capelin were successfully spawning on the shelf. The range expansion southward by capelin during cool periods is not unique. Frank et al. (1996) documented the arrival of capelin in the Bay of Fundy following the cooling in the 1960s and their disappearance when temperatures rose in the 1970s. Reported capelin catches in the Bay of Fundy prior to the 1960s all corresponded with periods of colder-than-normal water.

The distribution of snow crab (*Chionoecetes opilio*) also expanded during the recent cold period. It is a cold water species preferring temperatures of -1° to 3°C. Tremblay (1997) documents the range extension of this species on the north-eastern Scotian Shelf and attributed it to colder temperatures. He also noted that reduced predation from groundfish may have increased the survival and growth of juvenile and adolescent snow crab. Increases in the catch rates of shrimp (*Pandalus borealis*), another cold water invertebrate, have also been observed coincident with the cooling of the eastern shelf (DFO 1998).

Such changes in distributions of fish and invertebrates in response to changes in oceanographic conditions have significant implications to overall expectations within fisheries and to the overall trophic structure of the ecosystem. These sorts of changes cannot be controlled and must be recognized in the development and implementation of integrated management schemes.

4.4.1.8 Growth and Temperature: The growth of individual fish and invertebrates is temperature dependent. Studies have shown that mean bottom temperature is responsible for 90% of the observed (10-fold) difference in growth rates between different cod stocks in the North Atlantic (Brander, 1995). Warmer temperatures lead to faster growth rates. There is a 5-fold difference in the lengths-at-age of cod at 4 years old in the NW Atlantic, the largest from Georges Bank and the smallest from Labrador and eastern Newfoundland. Temperature accounts not only for the spatial differences in growth rates, but also, for temporal patterns. The low bottom temperatures during the last decade have been shown to be partly responsible for the observed decrease in size-at-age of cod on the eastern Scotian Shelf by Campana et al. (1995). Not only cod have been affected; the size-at-age of haddock has also decreased over the same period and the change is well modelled by changes in temperature.

Changes in the individual growth rate of exploited species, in response to changes in oceanographic conditions, must temper our expectations of yield in fisheries. In addition, these physical changes will have impacts on the overall productivity and trophic structure of the supporting ecosystem (see Section on Ecosystem Modeling below).

4.5 SHARKS

Sharks are represented by 19 shark species in the Canadian Atlantic waters, 5 of which can be considered to be common residents of the Eastern Scotian Shelf: the blue shark (*Prionace glauca*), porbeagle (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*), basking shark (*Cetorhinus maximus*) and the spiny dogfish (*Squalus acanthias*). All but the basking shark are targets of commercial and recreational fisheries. The population dynamics and life history of porbeagle sharks has been well studied, due to its importance in a directed fishery. Incomplete information is available for the other shark species, but all are subjects of ongoing research. Additional information on these and other Canadian shark species is available on the web site for the Shark Research Laboratory (www.marinebiodiversity.ca/shark/english/).

4.5.1 Porbeagle sharks

The porbeagle is a large cold-temperate pelagic shark species that occurs in the North Atlantic, South Atlantic and South Pacific oceans. The species range in the NW Atlantic extends from Newfoundland to New Jersey. Porbeagles move onto the Scotian Shelf in early spring and into the Gulf of St. Lawrence and onto the Grand Banks during the summer and early fall. Segregation occurs by sex and size. Mating occurs in the early fall off southern Newfoundland. Porbeagles move south and possibly into deeper water in late fall, but their winter distribution is unknown (Campana et al. 2002a).

Inshore fleet (< 33 m) JAN-JUN 1999-2000
Latitude
Offshore fleet (> 33 m) JAN-JUN 1999-2000
Latitude
Longitude

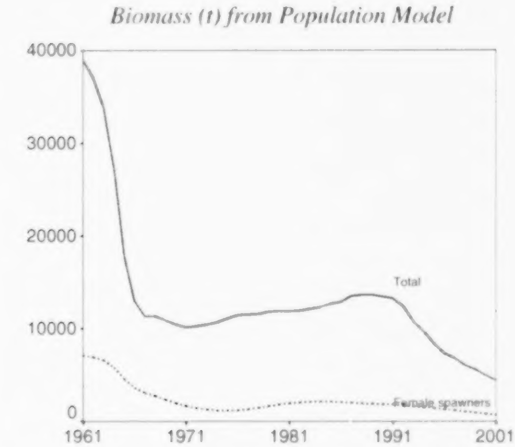
The porbeagle shark is common in pelagic and littoral zones, and inhabits water down to a depth of 370 meters. Off eastern Canada, it is most commonly found on the continental shelf or near the shelf edge, but sometimes comes inshore. It prefers cool waters and is usually found in temperatures between 5-10 degrees Celsius (Campana and Joyce 2004). It is the second most commonly observed large shark in Atlantic waters.

The porbeagle has a low fecundity, late age at sexual maturation and low natural mortality. Age at maturity is about eight years in males and about thirteen years in females (Jensen et al. 2002). In the northwest Atlantic, mating occurs from September through November, and live birth occurs eight to nine months later. Reproduction is thought to occur annually. Litter size averages about 4 young, and ranges from 2 to 6 young. The porbeagle life span is estimated to be between 25 and 46 years and generation time is about 18 years (Natanson et al. 2002; Campana et al. 2002b).

The porbeagle shark is an active and opportunistic predator feeding on a diverse group of fish and invertebrates throughout the water column. During the first half of the year the porbeagle's diet consists mainly of pelagic fish (especially mackerel, herring, and longnose lancetfish) and squid. Cod, flounder, lumpfish and other groundfish are commonly seen in stomachs taken in the fall, while many porbeagles are in shallower water. Other examples of less common prey include wolffish, spiny dogfish, sandlance, redfish, small crabs and the odd shellfish or gastropod. Overall, 91% of the weight of the stomach contents is fish (Joyce et al. 2002).

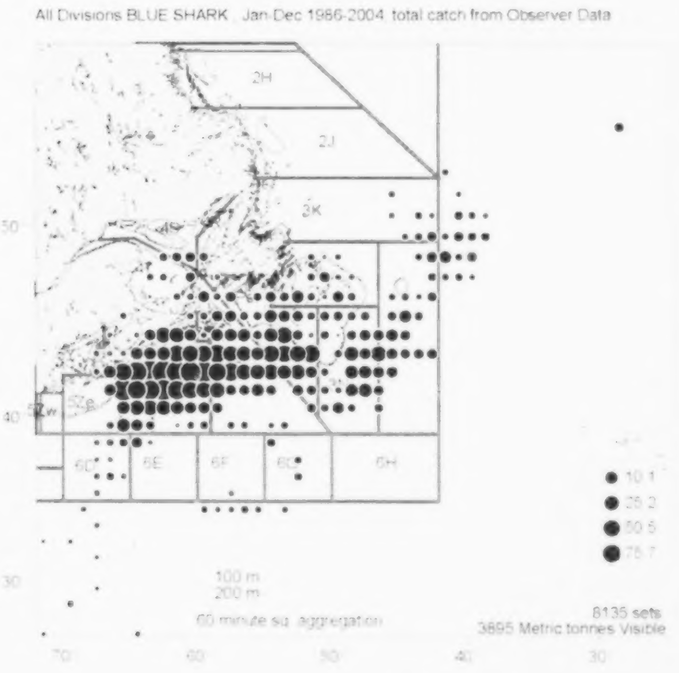
The directed fishery for porbeagle sharks in the Northwest Atlantic started in 1961 when Norwegian vessels began exploratory fishing on a virgin population off of eastern Canada. Average catches of about 4500 t per year in the early 1960s resulted in a fishery which collapsed after only six years, and which did not recover for another 25 years. However, the fishery appeared sustainable during the 1970s and 1980s when landings averaged 350t annually, and the population slowly recovered. Canada started a directed fishery for the porbeagle shark in 1991. However it was not until 1992 that the first fisheries management plan was implemented. Catches of 1000-

2000t throughout much of the 1990s appear to have once again reduced population abundance, resulting in lower catch rates and low numbers of mature females. Porbeagles are currently harvested through pelagic longline fishing at a depth of 50 to 150 meters. The main fishery is active in the spring and in the fall.



Commercial and biological data on the population have been integrated and used to reconstruct a perspective on the population dynamics and sustainable harvesting level of porbeagle off the eastern coast of Canada. Comprehensive stock assessments of the population concluded that commercial fishing was the only major cause of the population decline, and that the fishery in the 1960s was largely responsible. An updated and improved stock assessment was tabled in the spring of 2001, and was used as the basis for a new management plan (Campana et al. 2001). The current porbeagle population is seriously depleted and will require a greatly reduced fishing mortality if recovery is to occur. Due to the low productivity of the species, recovery will not be rapid. COSEWIC has recommended that porbeagle be listed as an endangered species, due to its low current abundance (Campana et al. 2003).

4.5.2 Blue Sharks


All Divisions BLUE SHARK , Jan-Dec 1986-2004 total catch from Observer Data
2H
2J
3K
5Zw
5Ze
6D
6E
6F
6G
6H
50
40
30
70
60
50
40
30
10.1
25.2
50.5
75.7
100 m
200 m
60 minute sq. aggregation
8135 sets
3895 Metric tonnes Visible

The blue shark occurs in the Atlantic, Pacific and Indian Oceans in both inshore and offshore waters. In Canadian waters the blue shark has been found in southeastern Newfoundland, the Grand Banks, the Gulf of St. Lawrence, the Scotian Shelf and the Bay of Fundy. The species occurs near the surface where water depths are greater than 50 m and temperatures between 10 and 20 degrees Celsius. It is probably the most common large shark seen in Canadian waters.

The blue shark is a viviparous species, nourishing the young in the uterus and giving birth to 25 to 50 live pups. Once the eggs have been fertilized there is a gestation period of between 9 and 12 months. Maximum lifespan is unknown at this time, but they are thought to live to at least 20 years of age. Seasonal migrations of blue sharks are typically associated with changes in water temperature. As waters warm, blue sharks migrate northward and inshore.

The diet of this shark includes many types of fish and squid, and may sometimes include seals (McCord and Campana, 2003). Although flatfishes make up part of the diet, blue sharks feed primarily on pelagic fish (mackerel and herring) and groundfish (cod and lumpfish). The diets of immature and mature sharks of both sexes differ, suggesting sexual segregation during feeding. Fish caught on longlines during fishing are often attacked and consumed by blue sharks, which in turn often become ensnared in the fishing gear. Blue sharks are opportunistic feeders and have been known to feed on dead whales and porpoises.

Blue sharks appear to be one of the most common of the large shark species in Atlantic Canada. Although caught frequently by recreational fishers, they are also caught unintentionally by commercial fishers (as bycatch). An analysis tabled in the fall of 2002 estimated that the weight of blue sharks caught as bycatch in commercial fisheries ranged between 1000-2000 mt per year. Thus the unreported catch was much greater than the ~50 mt reported as landed catch (Campana et al. 2002). A detailed analysis of the status of the blue shark population in Atlantic Canada examined year to year trends in the catch rates, size composition, maturity at size and mortality rates, both in shark derby catches and in commercial bycatches (Campana et al. 2004a). The results indicated that blue shark abundance has declined by about 5% per year, and mortality has increased, in the past decade. However, blue sharks are highly migratory, and it appears that there is a single population in the North Atlantic that is shared by multiple countries, with foreign fisheries responsible for >90% of the fishing mortality.

4.5.3 Shortfin Mako

Shortfin makos are a seasonally-resident large shark species in Atlantic Canada. Although avidly sought by recreational fishers, they are caught most often by commercial fishers directing for swordfish or tuna, who consider them to be a high-value bycatch. Tagging studies indicate that they are highly migratory, seasonal residents of Canadian waters, representing the northern extension of a North Atlantic-wide population centred at more southerly latitudes.

Shortfin makos can grow to lengths of 3.9 meters and an age of at least 24 years (Campana et al. 2004b). Developing embryos typically number 4-25 during the gestation period of 15-18 months, with the survivors being born live in the late winter and early spring. The diet consists mainly of squid and bony fishes including mackerels, tunas, bonitos and swordfish, but may also include other sharks, marine mammals and sea turtles.

Until recently, nothing was known of the population status of makos in either Canadian or North Atlantic waters. A recent population analysis indicates that annual catches in Canadian waters average 60-80 mt per year, which represents but a small part of that estimated for the North Atlantic population as a whole (Campana et al. 2004b). New ageing results indicate that the species grows more slowly than was reported previously, thus making the population less productive and more susceptible to overexploitation than has been reported. Although a catch rate index did not show any evidence of a decline in abundance, the average size of mako sharks in the commercial catch has declined since 1998, suggesting a loss of larger sharks. These results are broadly consistent with a published report of population decline, although it appears unlikely that current fishing rates in Canada are having an appreciable impact on the population.

4.5.4 Spiny Dogfish

The spiny dogfish is a small schooling shark that forms groups of hundreds or thousands of individuals of the same sex and size. It is one of the most abundant demersal shark species in Atlantic Canada. In June these sharks appear on the Scotian Shelf, in the Bay of Fundy and off southwestern Newfoundland. By July they move into the Gulf of St. Lawrence and into waters off of southern Labrador and around the rest of Newfoundland. By late fall most of the spiny dogfish migrate south out of Canadian waters and into the waters off of the U.S. Thus it is present only seasonally on the eastern Scotian Shelf. The spiny dogfish is tolerant of a wide range of salinities and can be found in estuaries. It moves throughout the water column from the surface to depths of 730 meters, but appears to prefer temperatures between 3 and 11 degrees C.

The spiny dogfish is long lived and slow growing and has an estimated life span of 25 to 40 years (Campana et al. 2006). Development is ovoviviparous with an extended gestation period of 18-22 months. Young are born in the warmer waters off of North Carolina or New England during the winter months. It is an omnivorous opportunistic feeder. In general the diet is comprised of small fishes such as capelin, cod, haddock, hake, herring, menhaden and ratfish. Spiny dogfish also eat invertebrates such as krill, crabs, polychaete worms, jellyfish, ctenophores, amphipods, squid and octopus. The current population status is unknown, although a U.S. stock assessment suggests that the number of mature females is at a dangerously low level. A cooperative industry-DFO research program is scheduled to release a population analysis in about 2008.

4.5.5 Basking Shark

The basking shark is a very large, slow-swimming filter feeding shark. In Canadian waters it is often seen during the summer and fall near and around the coastline. It ranges from Newfoundland, to the Gulf of St. Lawrence, on the Scotian Shelf, in the Bay of Fundy and south towards the U.S. border. The species is pelagic, occurring in both coastal and oceanic waters from 200 to 2000 m deep, but often straying inshore. In offshore areas, it is often found near oceanic fronts at temperatures between 11 - 24 degrees Celsius. Although its seasonal movements are not well known, these animals are believed to be highly migratory, possibly moving between Canadian and U.S. waters.

The basking shark can attain lengths of at least 10 meters, but the average size is 7-9 meters and may live up to 50 years. They are believed to be ovoviviparous, giving birth to live pups during the summer after a gestation period of 2-3 years. Basking sharks are planktonic feeders, feeding mainly on copepods and other crustaceans, fish eggs and larvae.

The population status of basking sharks in Canadian waters is unknown, but the species is listed as endangered in some parts of the world.

4.6 MARINE MAMMALS

Marine mammals inhabiting the Scotian Shelf are a diverse collection of taxa, varying in body size and life history. Nevertheless, in general they are large, long-lived species that are often abundant. Thus, we might expect some species to exert top-down control on the ecosystems within which they live (Bowen 1997). Given their large size and longevity, these species have evolved adaptations that enable them to deal with environmental variability over temporal scales less than their lifetimes and spatial scales less than their home ranges (Whitehead 1996).

Two groups of marine mammals, the Order Cetacea (whales and dolphins), and the Suborder Pinnipedia (seals) inhabit the Scotian Shelf and southern Gulf of St. Lawrence seasonally or throughout the year, including 23 species of cetaceans and 4 species of seals. For cetaceans, the number of species is likely underestimated (Kenney et al. 1997). Data on the seasonal abundance of cetaceans are most complete for the southern portions of the region, but even here there are few data on long-term trends (Kenney et al. 1997). For most species, these data are based on surveys conducted between 1979 and 1982 during the Cetacean and Turtle Assessment Program (CETAP 1982) and more recently from cetacean and turtle surveys conducted by the Northeast Fisheries Centre. Whitehead et al. (1998) provide a brief description of cetaceans on the eastern Scotian Shelf. With the exception of the northern bottlenose whale, there is little information on temporal changes in abundance of cetaceans within the eastern Scotian Shelf. Nevertheless, a number of the small odontocete species are thought to be common or abundant seasonally. In the Scotian Shelf and Southern Gulf of St. Lawrence, long-term trends in the abundance of marine mammals are available for several species. The best data are for the grey seal (*Halichoerus grypus*), however; there is also a long series of estimates for harp seal (*Phoca groenlandica*), a species whose distribution lies, for the most part, to the north of the Scotian Shelf.

4.6.1 Pinnipeds

The grey seal is a medium body-size and size-dimorphic member of the Family Phocidae, with males being about 50% heavier than females (McLaren, 1993). Body mass of both adult males and females varies throughout the year with dramatic losses of mass during the breeding season and moult, but both sexes are heaviest at the beginning of the breeding season (males average 290 kg, females average 207 kg; Beck et al. 2003). They are long-lived (~ 40 years) and thus individuals must have evolved to cope with variability at various temporal (months to decades) and spatial scales (<1 km to 1000 km). Most females give birth each year to a single pup, beginning at age 4 years and continuing for several decades. Although wide-ranging, grey seals are non-migratory, but do show seasonal changes in distribution. The changes are undoubtedly related to seasonal changes in distribution of prey (Bowen et al. 1993), but also reflect the aggregation of adults at a handful of land/ice breeding colonies throughout the region (Stobo et al. 1990). Locations from grey seals equipped with satellite tags show that they are mostly confined to the continental shelves off eastern Canada and the United States, although they do travel over deeper waters (Fig. 1, Bowen et al. 2005). Within this range, the areas < 100 m depth were used particularly often. Some offshore banks are clearly delimited by the distribution of locations, with Sable Island, Western and Middle Banks (areas near Sable Island) being used by most seals (Figure 15). Although this representation presumably provides a reasonable picture of population distribution and principle foraging areas, habitat use by individual seals show considerably variability (Austin et al. 2004).

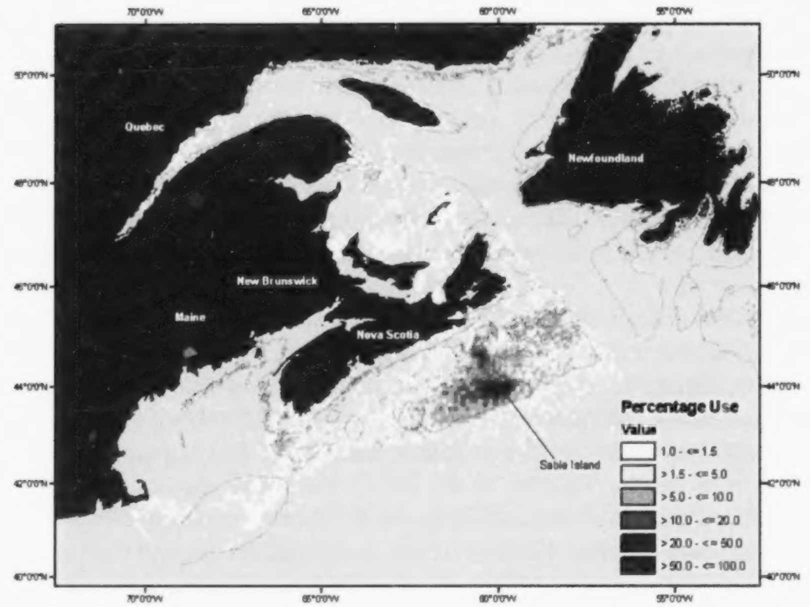


Figure 15. Annual distribution of adult grey seals based on locations of 70 animals fitted with Argos satellite tags on Sable Island (18 - May/June, 38 - Sept/Oct, 14 Jan). Only the first entry into each 5'x5'cell for each seal is represented. The 100 m isobath is indicated by a grey line.

An index of grey seal population trends, based on estimated pup production on Sable Island and the southern Gulf of St. Lawrence, covers the period 1962 to 1997 and from the early 1950s to 1997, respectively (Mansfield and Beck 1977, Zwanenburg and Bowen 1990, Mohn and Bowen 1996, Hammill et al. 1998, Bowen et al. 2003). Over the past three or four decades, the numbers of grey seals on the Scotian Shelf and Southern Gulf of St. Lawrence have increased dramatically. The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf (Figure 16). Population numbers of the Sable Island colony have increased exponentially at an annual rate of 13% per year for the past four decades (Bowen et al. 2003). This exponential increase, which cannot continue indefinitely, is not unexpected as grey seals in both areas were recovering from low numbers brought about by hunting. Short-term environmental influences are suggested in the Sable Island trends.

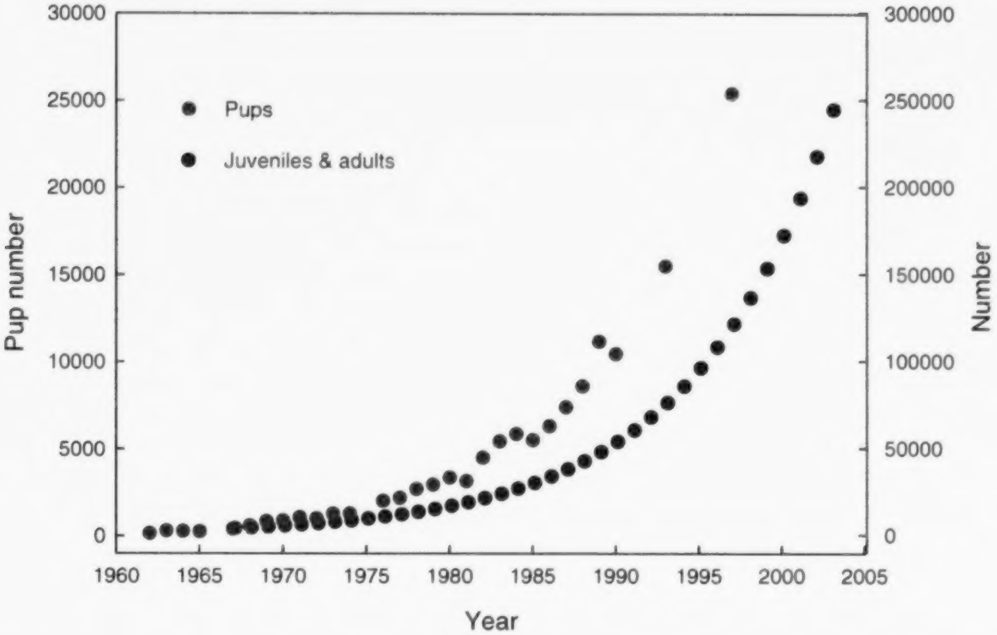


Figure 16. Observed trends in the number of pups and model estimates of the number of juveniles and adult grey seals associated with the Sable Island colony between 1962 and 1997.

Associated with changes in the abundance of grey seals have been changes in the predation mortality exerted by grey seals on commercially harvested and other finfish. The nature of these changes is somewhat uncertain. However, there is little information on grey seal diet prior to the mid-1980s and the functional form of grey seal predation to changes in prey abundance is unknown, thus predicting diet in the absence of diet information is problematic. Estimates of the composition of grey seal diets near Sable Island, derived from feces, indicate that sandlance was less common in the diet in the middle 1980s than during the 1990s (Mohn and Bowen 1996). Capelin was absent from estimates of the grey seal diet near Sable Island until 1994, but rapidly became a significant prey item in the diet of grey seals in 1995 and 1996, apparently partially replacing sandlance. Capelin virtually disappeared from the grey seal diet in 1997 and sandlance increased to account for about 80% of the diet (Bowen and Harrison; 2006).

Recent data from coastal sites along eastern Nova Scotia also point to changes in prey abundance as the cause of interannual differences in the diet of harbour seals (Bowen and Harrison 1996). Capelin was not identified in the diet from 1988 to 1990, but accounted for about 9% of the diet by wet weight in 1992. This increase of capelin in their diet was coincident with a marked increase in the local abundance of capelin from about 1 to 9 capelin per tow in 1985 to 1990 to over 90 capelin per tow in 1992 (Frank et al. 1996).

Estimates of grey seal diets based on the recovery of prey remains in stomach contents (e.g., Bowen et al. 1993) and from feces can be biased in a number of ways (Bowen and Siniff 1999). To attempt to overcome some of the biases associated with traditional methods of estimating diets, over the past decade a method which uses seal and prey fatty acids has been developed (Iverson et al. 2004). This method can provide quantitative estimates of diet that do not depend on the recovery of prey hard parts. This new method, termed Quantitative Fatty Acid Signature

Analysis (QFASA), indicated that during the 1990s grey seals fed primarily on sandlance and redfish, followed by several species of demersal fishes such as flounders, skates and gadoids such as pollock and Atlantic cod (Bowen et al. 2005, Beck et al. in review). Although cod was eaten, it was consumed by very few seals accounting for only 0-4% of the diet seasonally (Beck et al. in review).

Mohn and Bowen (1996) modeled the impact of grey seal predation mortality on Atlantic cod on the Eastern Scotian Shelf off Nova Scotia over the period 1967 to 1994. They used two models to describe the response of grey seal predation to changes in cod abundance under two assumptions about the level and pattern of age-specific natural mortality of cod. Under either model (constant ration or proportional ration), grey seal predation mortality was only 10-20% of the estimated mortality caused by the fishery. The models generally predicted that future recruitment of age 1 cod to the cod population would be significantly reduced due to grey seal predation, but these predictions were quite sensitive to the assumption that seal predation mortality was additive. It is not known if this assumption is true. Mohn and Bowen (1996) concluded that uncertainty in assessing the impact of grey seal predation on Atlantic cod (*Gadus morhua*) resulted from: the lack of information on the natural mortality rate of young cod, the nature of the interactions (i.e., additive vs. compensatory) among the components of natural mortality on young cod, and the functional response of grey seals to changes in prey abundance.

The Mohn and Bowen predation model is being updated using new information on grey seal habitat use, seasonal energy requirements and diets to provide current estimates of the impact of grey seal predation on cod dynamics on the Scotian Shelf.

Harbour seals are widely distributed on the eastern Scotian Shelf at both coastal sites and on Sable Island. Less is known about seasonal movements of harbour seals, but like grey seals, the species is non-migratory. Flipper tag recoveries indicate that young of the year disperse broadly throughout the Scotian Shelf, but data from a few satellite tags indicates rather localized movements of adults.

Harbour seal pup production on Sable Island has been monitored since 1973 and the number of pups born steadily increased through the late 1980s (Figure 17). However, during the 1990s pup production fell rapidly and dramatically as a result of increased shark predation and presumed competition for food from the expanding grey seal population (Lucas and Stobo 2000, Bowen et al. 2003). Coincident with the decline in number was an increase in the mean birthing date of females (red symbols), suggesting nutritional stress prior to the breeding season, perhaps also caused by competition for food by grey seals. By 2002, less than a dozen pups were born on Sable Island and in all likelihood Sable Island will become a non-breeding site in the future.

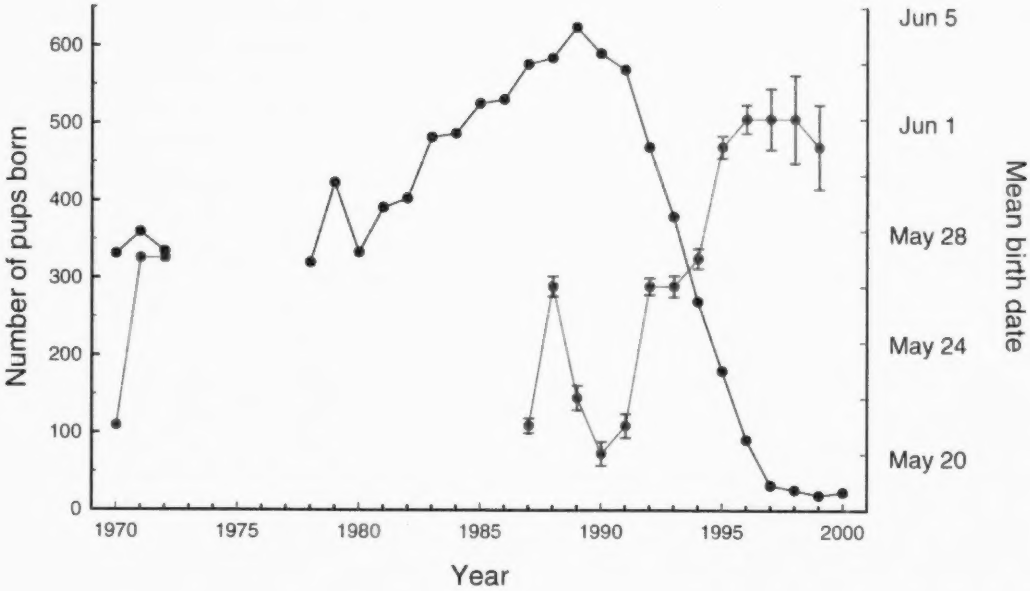


Figure 17. Number of harbour seal pups born on Sable Island (blue). Data from 1970-72 and from 1978-97 are from Boulva and McLaren (1979), W. T. Stobo (pers. comm.), and Lucas and Stobo (2000) respectively. Also shown are mean birth dates for 1970-72 and from 1987 to 1999 (red symbols, from Bowen et al. 2003).

Considerably less is know about the abundance of harbour seals along coastal Nova Scotia, but numbers are thought to be small compared to grey seals. There are no recent estimates of abundance. However, the abundance of harbour seals has increased over the past several decades along the coast of Maine (Waring et al. 2000).

Like grey seals, harbour seals are generalist predators consuming a wide variety of both pelagic and demersal fish species (Bowen and Harrison 1996). Along coastal Nova Scotia, diet varied both geographically and among years, but herring, pollock, cod and squid were among the more important prey species. At Sable Island, sandlance was the predominant prey of adult males during the breeding season followed by flounders and capelin (Iverson et al. 2004).

4.6.2 Cetaceans

As noted above, there are few species for which either population size or trends in abundance are available on the Scotian Shelf. Thus, those species highlighted below are not necessarily more ecologically important or sensitive to human actions, but are simply the species for which we have some information. Waring et al. (2000) review the population status for cetaceans in the northwest Atlantic (their Table 1) but in most cases it is not possible to determine what fraction of the population might use the Scotian Shelf.

Estimates of abundance of some cetaceans are available from the 1995 summer line-transect abundance survey (the aerial portion) conducted by the Northeast Fisheries Science Centre. Estimates were provided by Dr. Debra Palka, NMFS, and are detailed in Bundy (2004, Appendix 3). The following whales and dolphins were sighted in the eastern Scotian Shelf part of the survey: fin whale, minke whale, humpback whale, sperm whale, pilot whale, common dolphins and Atlantic white-sided dolphin. The abundance of each species was multiplied by the mean weight of each species to give biomass, and this biomass was adjusted for the residency period of each species on the eastern Scotian Shelf to give average annual estimates of biomass (Table 1).

Table 1. Abundance, mean weight, residency time and biomass estimates of cetaceans on the eastern Scotian Shelf in 1995-2000 (from Bundy 2004).

	No./km^2	Mean body weight (t)	Residence[1]	Density (t/km^2)	Total No.	Total Biomass (t)
Humpback	0.0074	31	0.25	0.0574	189	5868
Sperm	0.0006	40	0.43	0.0104	27	1062
Minke	0.0023	5.6	0.27	0.0034	63	350
Pilot	0.0323	1.4	0.50	0.0226	1669	2308
Fin	0.0071	38.5	0.55	0.1493	397	15276
white-sided dolphin	0.2588	0.4	0.55	0.0171	14559	1747
common dolphin	0.0130	0.3	0.25	0.0002	333	22
TOTAL	0.3189			0.2603	17236	26634

[1] residence is the proportion of the year spent in the study area. These are estimates based on information in the literature.

These estimates are subject to several sources of uncertainty. The abundance estimate from the aerial survey is negatively biased because it was assumed that the probability of detecting an animal, if it were on the transect line, was 1, and there were no dive time corrections (see Bundy 2004, Appendix 3 for more details). Abundance may fluctuate through time depending on what food sources are available on the Scotian Shelf. The residency times are estimates based on information in the literature and consultation with experts. None are considered accurate.

Northern bottlenose whales (*Hyperoodon ampullatus*) are consistently found through the year in the Gully, a prominent submarine canyon on the edge of the Scotian Shelf. Vessel-based surveys of bottlenose whales have been conducted since 1988. Sighting rates (i.e., sightings/hour searching) between 1988 and 1999 have varied among years, but without evidence of trend, and there was no significant difference in population estimates for 1990, 1996 and 1997 (Gowan et al. 2000). The most recent analysis, based on re-sightings of naturally marked individuals, indicates a population size of about 130 whales (Gowan et al. 2000). The small size of the Gully population and its persistent use of a small, bathymetrically unique ocean area make northern bottlenose whales vulnerable to human disturbance.

4.7 SEABIRDS

Seabird distribution on the Scotian Shelf has been described by Brown et al. (1975) and Huettmann (2000). The eastern Scotian Shelf is known to carry large numbers of wintering dovekie (*Alle alle*) (Brown 1988), and high numbers of sooty *(P. griseus*) and greater shearwater *(P. gravis*). For species like thick-billed murre (*Uria lomvia*), common murre (*U. aalge*), Atlantic puffin (*Fratercula arctica*), northern fulmar (*Fulmarus glacialis*), glaucous and Iceland gull *(Larus hyperboreus, L. glaucoides*), the area generally constitutes their southern wintering range. During spring and fall, the shelf also lies on the flyway for Canadian herring gulls (*Larus argentatus*), great black-backed gulls *(L. marinus*), northern gannets (*Morus bassanus*). During the summer (northern hemisphere breeding season), the Shelf is also important for Leach's storm petrels (*Oceanodroma leucorhoa*), and also for Wilson's storm petrel (*Oceanites oceanicus*) migrating from the southern hemisphere. While the latter does not breed in the northern hemisphere, it is among the most abundant seabird species in the world. Sightings of birds from other distributional ranges and hemispheres occasionally occur in the study area, too, such as Cory's and Manx shearwater (*Caleonectris diomedea, Puffinus puffinus*) (the latter is an increasing new breeding population), black skimmer (*Rynchops niger*), Flea's petrel (Hooker and Baird 1997), south polar skua (*Catharacta maccormicki*) and others. For further details on background and general ecology of seabirds and the study area, see Nettleship and Birkhead (1985), Furness and Monaghan (1987), Gaston and Jones (1998), Huettmann and Diamond (2000) and Huettmann (2000).

Quantitative estimates of abundance, biomass and prey consumption of seabirds in the eastern Scotian Shelf are reported by Heuttman (2003). The data used for this study were derived from the PIROP (Programme des Récherches sur les Oiseaux Pélagiques) database, the largest and most detailed data set on seabird abundance and distribution for the shelf (for details see Brown et al. 1975, Lock et al. 1994). The database covered the period from 1966-1992 and all estimates were averaged over this period, so no estimates of trends in abundance are possible. The 10 main species found on the eastern Scotian Shelf and their biomass, seasonally weighted are shown in Table 2.

Observations of changes in the seabird populations in the Gulf of Maine were observed to have been the result of changes in zooplankton populations. While seabirds may not be a significant biomass in the marine ecosystem they may be a useful indicator of some changes in the marine ecosystems. If the diet preferences of these birds has been sufficiently well characterized, fluctuations in bird population dynamics could be used to monitor changes in prey population. This is particularly important where these prey populations are species which are also used as prey by other ecosystem components

Table 2. Estimated annual biomass of seabirds on the eastern Scotian Shelf (Bundy 2004).

Seabird species	Biomass (t)
Greater shearwater	304
Herring gull	282
Wilson's storm petrel	8
Great black-backed gull	281
Northern fulmar	76
Black-legged kittiwake	54
Leach's storm petrel	3
Dovekie	19
Thick-billed murre	43
Sooty shearwater	10
Total Biomass	1079
Density (t km^{-2})	0.0120

4.8 OTHER BIOTA

Within the ESSIM area there are areas and species groups for which our understanding is rudimentary at best. A prime example is the continental slope fauna. At present we have estimates of fish species composition from only a small number of trawl observations relative to the number of observations on the continental shelf; and most of these apply only to the top 1000 m of the continental slope, which reaches depths of 4000 meters and more. The following tables give some indication of demersal fish species composition for the upper slope; however, we have no knowledge of the changes in population size of individual species or of changes in species composition. The observations of species occurrence and relative abundance are expressed as total numbers caught within the surveys conducted in the ESSIM slope area between 1982 and 1987 (Table 3).

Table 3. Finfish species composition of the Scotian Slope (1982-1987) based on the result of trawl surveys.

Shallow Water Species (Decreasing abundance beyond 180 m) –
column headings refer to depth ranges i.e. LT180 is water less than 180 m in depth and so on.

Species	LT180	LT360	LT540	LT 720	LT900
AMERICAN PLAICE	778.24	242.93	23.93	0.92	2.00
COD(ATLANTIC)	4781.17	1833.4	133.34	0.00	0.00
HADDOCK	3102.76	1558.1	33.52	0.00	0.00
LONGHORN SCULPIN	9.48	2.12	0.00	0.00	0.00
LUMPFISH	92.96	0.00	0.00	0.00	0.00
MACKEREL(ATLANTIC)	20.20	0.00	0.00	0.00	0.00
SEA RAVEN	12.93	0.00	0.00	0.00	0.00
SMOOTH SKATE	88.79	46.37	0.97	0.00	0.00
STRIPED ATLANTIC WOLFFISH	353.55	166.29	32.39	0.00	2.92
THORNY SKATE	1037.75	495.45	77.44	6.25	0.00
WINTER SKATE	6801.12	613.79	50.85	0.00	0.00
YELLOWTAIL FLOUNDER	38.45	10.51	1.09	0.00	0.00

Upper Slope (Decreasing abundance beyond 360 m)

Species	LT180	LT360	LT540	LT 720	LT900
FRECKLED SKATE	0.00	1.03	0.00	0.00	0.00
LITTLE SKATE	0.97	2.12	0.00	0.00	0.00
MONKFISH,GOOSEFISH,ANGLER	50.53	345.07	346.12	4.67	0.00
NORTHERN HAGFISH	2.09	3.95	1.59	0.00	0.00
OCEAN POUT(COMMON)	0.00	1.03	0.00	0.00	0.00
POLLOCK	4659.01	5109.73	37.75	0.00	0.00
SHORT-FIN SQUID	0.00	4.25	1.09	0.00	0.00
SILVER HAKE	1573.69	2452.44	81.04	2.42	0.00
SPINY DOGFISH	17.94	43.79	4.67	0.00	0.00
SPINY EELS (NS)	0.00	1.03	0.00	0.00	0.00
SQUIRREL OR RED HAKE	1.17	10.50	5.00	0.00	0.00
WHITE HAKE	610.43	3578.83	393.00	41.59	2.92
WITCH FLOUNDER	227.17	864.27	39.60	11.73	0.97
WRYMOUTH	4.18	0.00	0.97	0.00	0.00

Slope (Most abundant > 360 < 900)

	LT180	LT360	LT540	LT 720	LT900
AMERICAN STRAPTAIL GRENADIER	0.00	0.00	1.09	0.00	0.00
APRISTURUS LAURUSSONI	0.00	0.00	2.33	0.00	0.00
ARCTIC EELPOUT	0.00	0.00	1.09	0.00	0.00
ARGENTINE(ATLANTIC)	0.92	31.65	53.70	2.01	0.00
BACKFIN TAPIRFISH	0.00	0.00	9.99	0.00	0.00
BARNDOOR SKATE	0.00	0.00	23.33	0.00	0.00
CUSK	0.00	70.40	86.34	0.00	0.00
EELPOUTS(NS)	0.00	1.03	0.00	1.25	0.00
GRAY'S CUTTHROAT EEL	0.00	0.00	0.00	2.34	0.00
HALIBUT(ATLANTIC)	241.27	435.29	132.43	9.36	110.42
JENSEN'S SKATE	0.00	0.00	0.00	1.09	0.00
KNIFENOSE CHIMERA	0.00	0.00	0.00	2.50	0.00
LANTERNFISH (NS)	0.00	0.00	0.80	0.00	0.00
LONGFIN HAKE	18.34	207.88	421.79	69.16	9.83
LONGNOSE GRENADIER	0.00	0.00	0.00	1.09	0.00
MARLIN-SPIKE GRENADIER	0.00	10.09	16.34	9.38	6.07
NORTHERN WOLFFISH	7.37	9.26	12.27	27.73	0.00
OFF-SHORE HAKE	1.93	14.82	211.32	33.67	2.92
REDFISH UNSEPARATED	471.81	10705.77	34622.05	3483.81	565.13
ROCK GRENADIER(ROUNDNOSE)	0.00	0.00	4.37	1.09	0.97
ROUGHNOSE GRENADIER	0.00	0.00	3.67	0.00	0.00
ROUND SKATE	0.00	0.00	1.59	0.00	0.00
SHORTSPINE TAPIRFISH	0.00	0.00	0.00	1.09	0.00
SNUBNOSE SLIME EEL	0.00	0.00	1.17	0.00	0.00
SPINY EEL	0.00	0.00	23.25	4.84	1.09
SPINYTAIL SKATE	0.00	0.00	0.00	50.31	0.00
SPOTTED WOLFFISH	10.07	13.38	18.57	1.09	0.00
TRUNKFISH	0.00	0.00	5.83	0.00	0.00
TURBOT,GREENLAND HALIBUT	5.25	6.18	65.56	89.36	21.59

Our knowledge of fish diversity in waters beyond 1000 m is even more limited. The following table (Table 4) presents the most up-to-date estimate of demersal fish composition at depths to 3000 m. This estimate is based on the results of a single survey.

Table 4. *Alfred Needler* cruise N156, 7-13 August, 1991: finfish species caught by GILLNETS off Emerald Bank and The Gully, ranked by abundance within area and depth zone. (Top five species only ranked, + = presence.). From Zwanenburg (ed) 1998, data provided by R.G. Halliday.

SPECIES		RANKING		
			The Gully	
Scientific Name	Common Name	Emerald Bank 1000 -2000 m	1000 – 2000m	2000 – 3000 m
Centroscyllium fabricii	black dogfish	1	1	-
Centroscymnus coelolepis	Portuguese shark	2	3	3
Hydrolagus affinis	deepwater chimaera	3	5	1
Etmopterus princeps	rough sagre	4	+	-
Reinhardtius hippoglossoides	Greenland halibut	5	4	5
Antimora rostrata	blue hake	+	+	2
Macrourus berglax	roughhead grenadier	+	2	4
Urophycis tenuis	white hake	+	-	-
Harriotta raleighana	longnose chimaera	+	+	-
Hippoglossus hippoglossus	Atlantic halibut	+	-	-
Raja jenseni	Jensen's skate	+	+	+
Alepocephalus sp.	slickhead	+	-	-
Simenchelys parasiticus	snubnose eel	+	-	-
Raja spinicaudata	spinytail skate	-	-	+

In addition to the demersal fish species there are a minimum of 75 species of epipelagic, bathypelagic, and neritic species that occur in slope waters (see Zwanenburg *in* Harrison and Fenton 1998 for a listing of species). These fishes probably comprise a mixture of resident species, migrants, and vagrants from more southerly or oceanic populations. Again we have no real understanding of the dynamics of either species composition or of the changes in abundance within any one species. There are also indications that a large number of squid species occur on or around the Scotian Slope. A compilation of species occurrences and source references are provided at http://www.cephbase.utmb.edu/biogeo/spatialsrch.cfm .

5.0 HUMAN IMPACTS

To this point we have examined the nature of the shelf ecosystem and its components, with emphasis on natural interactions between species and between biota and their habitats. We have also discussed the impacts of fishing on targeted organisms and associated bycatch, but have not examined other impacts of human activities on the ecosystem. This section will discuss the difficulties in separating natural variability from the impacts of fishing pressure, and collateral environmental damage from fishing and other activities.

5.1 ENVIRONMENT VERSUS EXPLOITATION

We have described the effects of fishing and changes in environmental conditions on size structure, growth, and distribution of a number of fish and invertebrate species of the Scotian Shelf as if each acted independently of the other. In fact they work in concert. The effects attributed to exploitation are really the effects of exploitation operating against the backdrop of changing distribution patterns and changing growth rates. These are, in turn, responding to changes in environmental conditions. The effects attributed to environmental changes have been modified by the underlying impacts of exploitation. These effects do not occur in isolation.

Since changing environmental conditions are beyond human control (save perhaps for the levels of greenhouse gas emission) the effects of these forcing factors on not only the exploited species, but also on the exploited ecosystem as a whole, need to be used to modify patterns and levels of exploitation. At present, the formulation and implementation of harvest plans take no account of the environmental effects on productivity of individual populations, the collateral effects of fishing, on non-target organisms, or the effects on the physical environment.

There are significant difficulties standing in the way of this objective. The relative effects of changes in environmental conditions, compared to fishing (or other anthropogenic impacts) are difficult to quantify and to disentangle. In a previous section, we showed that decreased size at age of a single species (haddock) was highly correlated with decreased ambient temperature on the eastern Scotian Shelf. We also demonstrated that the change in the average size of a suite of exploited species is inversely related to fishing effort. This decrease in size occurred both on the eastern shelf, where temperature decreased in the latter 1980s through early 1990s and on the western shelf, where temperatures remained relatively stable over this same period. It is noteworthy that the overall rate of decline in Integrated Community Size Frequency was more rapid on the eastern shelf than the western shelf, despite much higher levels of fishing effort on the latter. This difference may point to the mitigating impact of the warmer temperatures and higher growth rates of the western shelf. The relative impacts of exploitation and environmental conditions may be illuminated by a more detailed analysis of these observed differences in response.

A second problem relates to the establishment of ecosystem level metrics by which to judge both the impacts of exploitation and environmental changes. From 1977 to the present, the only metrics used in fisheries assessments were related to single species (fishable biomass, recruitment, fishing mortality) and of these, fishing mortality was paramount. The estimation of the rate of exploitation of target species, as evidenced by the fishing mortality rate, formed the basis of most management decisions. More recently, consideration has been given to the level of spawning stock biomass (SSB) in that levels of SSB, below a predetermined threshold, have resulted in the cessation of fishing until such time as the spawner biomass rebuilds. There are, however, no ecosystem level metrics, or targets, currently being used in the management of Scotian Shelf fisheries. If management of fisheries in Canada, and worldwide, is to move beyond the isolationist single species model and take into account the collateral impacts of fishing and changing environmental conditions, it is essential that such metrics and targets continue to be explored, developed, and implemented.

5.2 BYCATCH

A major collateral impact of fisheries is their bycatch, that is, the catch of non-target organisms during actual fishing operations. Fishing is one of the most significant activities that humans carry out in marine ecosystems. At present, approximately 15 x 10^6 km^2 of the world's continental shelves are trawled annually (Watling and Norse 1998), and the total removals of fish and invertebrates amount to some 100 million tonnes per annum. Between 17 and 40 million tonnes of this total is discarded (Alverson et al 1994). It consists of a diverse array of vertebrates and invertebrates, most of which remain unidentified and unrecorded, and the great majority of which are dead. Impacts on fish communities are readily documented and include changes in community dominance, and size spectra (e.g. Haedrich and Barnes; 1997, Bianchi et al.; 2000, Zwanenburg 2000). Impacts on other communities and at other trophic levels remain relatively undocumented.

Bycatch information for non-target but commercially valuable species exists for all of the fisheries of the Scotian Shelf for the past 20 or more years, since these species are actually landed. By-catch information on non-target, non-commercial, species exists for a much smaller subset of these fisheries, from on-board observers and from commercial index surveys conducted by the fishing industry. Landings information gives only a nominal indication of the impacts of fisheries, in that they only record what is actually landed, not what was initially caught. All fisheries discard unwanted species, both undersized specimens of targeted species, and all size classes of non-target species.

Species catch profiles collected during actual fishing operations give a relatively complete picture of the catch spectrum for any fishery; however these data are difficult and costly to collect and are available for only a small subset of fisheries. The primary sources of these data are the (Department of Fisheries and Oceans) DFO On-board observer program (in operation since 1978), and a number of more recent industry / DFO survey initiatives which carry on-board observers during fishing operations. The long-term observer program deployed most of its observers on foreign vessels operating in Canadian waters until the early 1990s. Presently industry /DFO surveys cover mainly small boat fisheries on restricted portions of the Scotian Shelf. To fully characterize the catch profiles of all extant fisheries would require augmenting and /or redirecting the present cadre of observers.

Both landings and onboard observer information are important to the development of fisheries ecological profiles. The former should be augmented to include the full range of species caught while the latter should be expanded to allow us to estimate catch profiles for all fisheries.

5.2.1 Scotian Shelf Observer Data

We used information on catch composition obtained by observers on-board commercial fishing vessels fishing the Scotian Shelf between 1978 and 2001 to estimate commercial fishery catch profiles. The basic unit of information extracted from these data was the total amount of each species caught during a particular fishing set. Catch profiles were aggregated by 0.5-degree squares, year, gear type, and vessel tonnage to facilitate analysis and to test for differences in catch profiles. Catch profiles are available for both Canadian and foreign vessels operating on the Scotian Shelf. Here we concentrate on the analysis of domestic stern trawler catch profiles (Table 5)

Table 5. Number of sets observed for stern trawlers fishing the Scotian Shelf for the period 1978 to 2001. Note the significant decline in the number of observations for large trawlers after 1997 coincident with the exclusion of much of the foreign fleet (tonnage class 4 and greater represents those vessels with a GRT > 150 tonnes).

	Tonnage Class								
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
1978					50	578			**628**
1979					106	1000			**1106**
1980					141	2104			**2245**
1981					331	2534			**2865**
1982				3	412	1713			**2128**
1983					291	1734			**2025**
1984					320	1494			**1814**
1985			22	23	152	2413	28		**2638**
1986				4	14	1373		204	**1595**
1987				11	118	1608	25	464	**2226**
1988				18	364	2234		331	**2947**
1989				122	225	2493	11	420	**3271**
1990		7	128	367	581	4323	3	191	**5600**
1991		20	158	361	107	3578	169	530	**4923**
1992		17	56	371	196	2449	215	7	**3311**
1993		64	332	779	160	1802	26		**3163**
1994			114	1031	155	2058			**3358**
1995			105	613	49	1542			**2309**
1996			188	1324	72	937			**2521**
1997			36	707	15	993			**1751**
1998		15	96	496	32	224			**863**
1999		202	162	404	123	456			**1347**
2000	6	216	430	673	61	120			**1506**
2001	21	379	409	566	18	218			**1611**
	27	**920**	**2236**	**7873**	**4093**	**39978**	**477**	**2147**	**57751**

Cluster analysis and non-metric multidimensional scaling were used to determine if there were patterns in the catch profiles for each of the year, gear, and tonnage class aggregations. An initial analysis of the catch profiles for Canadian stern trawlers indicated significant differences between large (> 150 Gross Registered Tonnes [GRT]) and small stern trawlers (< 150 GRT). For the present we have focussed on the large stern trawler data set since data for this class of vessel represents the widest and most consistent coverage of the Scotian Shelf.

Cluster analysis indicated two time periods, evident in the catch profile for the Scotian Shelf. ANOSIM results show that catch profiles from 1978 to 1992 were significantly different from those for 1993 – 1997 (Figure 18).

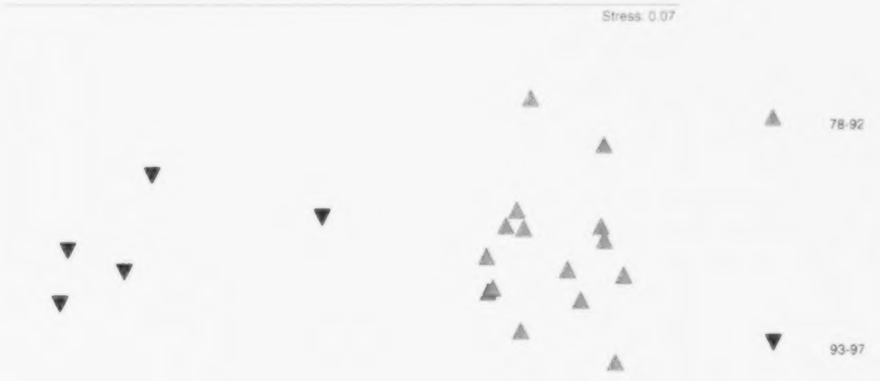


Figure 18. Non-metric multi-dimensional scaling analysis of yearly catch profiles for large (GRT > 150 t) Canadian stern trawlers fishing on the Scotian Shelf between 1978 and 1997.

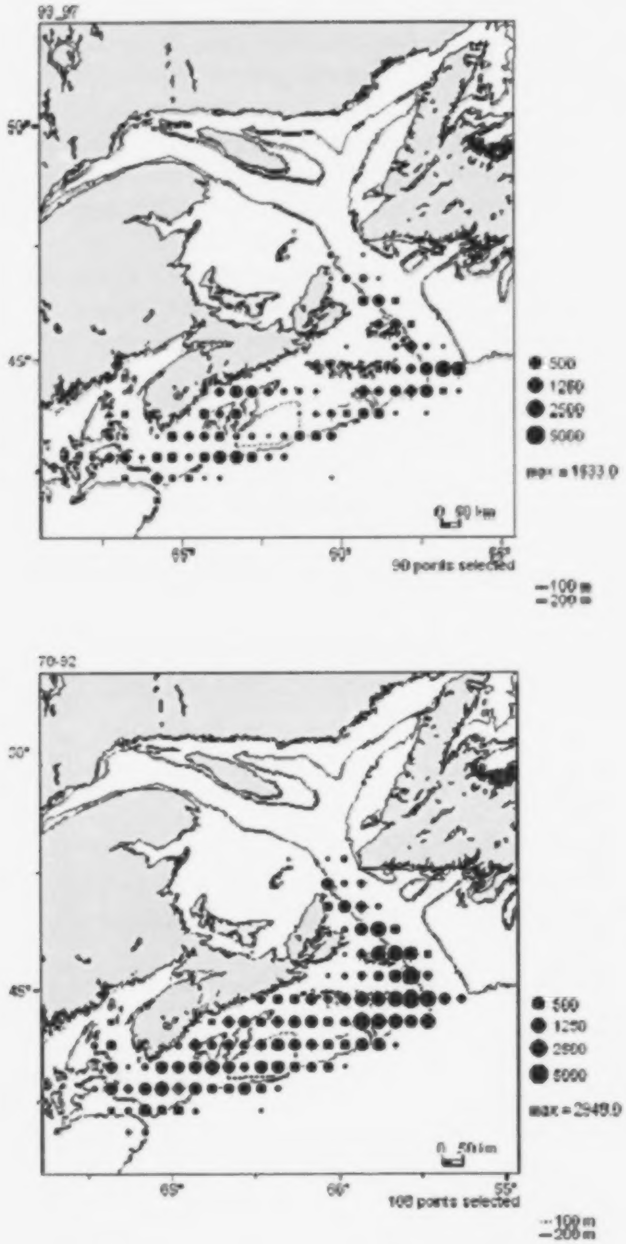
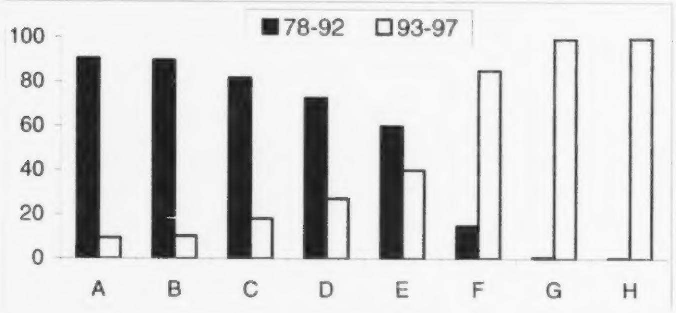


Figure 19. Distribution of observed sets for large (>150 t GRT) Canadian stern trawlers fishing the Scotian Shelf during the period 1978 -1992 (bottom) and 1993 - 1997 (top).

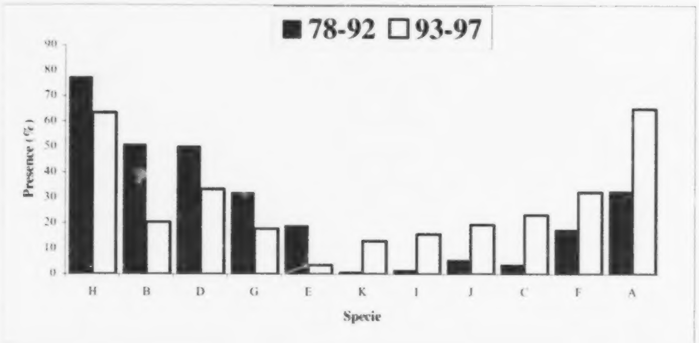
We observed that the distribution of fishing effort changed significantly after 1993 (Figure 19). This is reflection of the fact that the fishery on the eastern Shelf was put under moratorium in 1993 (for cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*) with only redfish *Sebastes*, halibut *Hippoglossus hippoglossus*, and white hake *Urophycis tenuis* fisheries in operation. The moratorium remains in effect.

We used ANOSIM (Clarke and Warwick 2001) to test the similarity / dissimilarity of species composition in a series of samples, in this case catch composition in the two time periods were tested. Catch compositions for the two time periods differ significantly with regard to both the average weight of species and with regard to the frequency of occurrence of species. For those species that contribute most to the dissimilarity of the catch profiles for these two periods, the average weight of cod and haddock caught in the earlier period was larger than in the second period (Figure 20). It also shows that redfish and grenadiers make up a larger portion of the catches in the latter period. With regard to frequency of occurrence we observe that the frequency of cod, haddock, skates (*Raja* spp), American plaice (*Hippoglossoides platessoides*), and yellowtail flounder (*Limanda ferruginea*) all decrease, while the generally deeper water species increase in frequency (Figure 21).



HADDOCK	A
COD(ATLANTIC)	B
AMERICAN PLAICE	C
SKATES (NS)	D
POLLOCK	E
REDFISH UNSEPARATED	F
ROCK GRENADIER(ROUNDNOSE)	G
SILVER HAKE	H

Figure 20. Contrast of catch profiles for large stern trawlers fishing the Scotian Shelf during the periods 1978 – 1992 versus 1993 – 1997. This contrasts catch profiles based on the average weight per set for those species that contribute to 90% of the dissimilarity between the two periods.



COD(ATLANTIC)	H
SKATES (NS)	B
HADDOCK	D
AMERICAN PLAICE	G
YELLOWTAIL FLOUNDER	E
TURBOT,GREENLAND HALIBUT	K
ARGENTINE(ATLANTIC)	I
THORNY SKATE	J
WHITE HAKE	C
HALIBUT(ATLANTIC)	F
REDFISH UNSEPARATED	A

Figure 21. Contrast of catch profiles for large stern trawlers fishing the Scotian Shelf during the periods 1978 – 1992 versus 1993 – 1997. This contrasts catch profiles based on the frequency per set for those species whose contributions changed more than 10% between periods.

5.2.2 Translating Catch Profiles to Exploitation Profiles (the indicator)

Ideally the catch profiles for each area identified would allow us to estimate an exploitation rate for each species in the area (given that we have an estimate of biomass for each species), however since they do not represent 100% of the fishery (since not all fisheries are observed), we must first estimate total catches for all of the species encountered. This would be relatively simple if total landings for all species were recorded in the national statistics. However, landings are only recorded for the commercially exploited species. This necessitates estimating the catches for the non-commercial species in the catch profiles. For any given non-commercial species in a specific catch profile:

$$\text{Total Catch non-com spp} = \frac{1}{\sum \text{Catch}_{\text{Spcom}} \,/\, \sum \text{Landings}_{\text{Spcom}}} \; * \sum \text{Catch}_{\text{Spnoncom}}$$

where $\sum \text{Catch}_{\text{Spcom}}$ is the sum of the observed catch of a commercial species in the catch profile, $\sum \text{Landings}_{\text{Spcom}}$ are the sum of the reported landings for that species from the area gear time period to which the catch profile applies, and $\sum \text{Catch}_{\text{Spnoncom}}$ is the sum of the catch of the non-commercial species of interest in the catch profile.

There is a further complication in that the spatial resolution of landings data prior to 1992 was restricted to NAFO unit areas. As an initial integrated estimate of an overall exploitation profile, we have estimated an overall Eastern Scotian Shelf catch profile based on observed catches for the period 1978 – 1992. The number of species included was restricted to those fish species for which we have biomass estimates. Harley and Myers (2000) have derived catchability corrected biomass estimates for the majority of the most abundant species encountered in the summer trawl survey of the eastern Scotian Shelf.

Exploitation for each species was estimated as Catch / Biomass. The exploitation profile for the eastern shelf, based on the catch profile derived from onboard observation of catches extrapolated to total catches as outlined above, and using q-corrected estimates of biomass for each species is shown in Figure 22.

These analyses indicate that the overall impact of the trawl fisheries on the Scotian Shelf are not restricted to the commercially important species but extend to between 50 and 400 species. We estimate that they exert exploitation rates ranging from less than 1% of estimated biomass per annum to values in excess of 50% of estimated biomass.

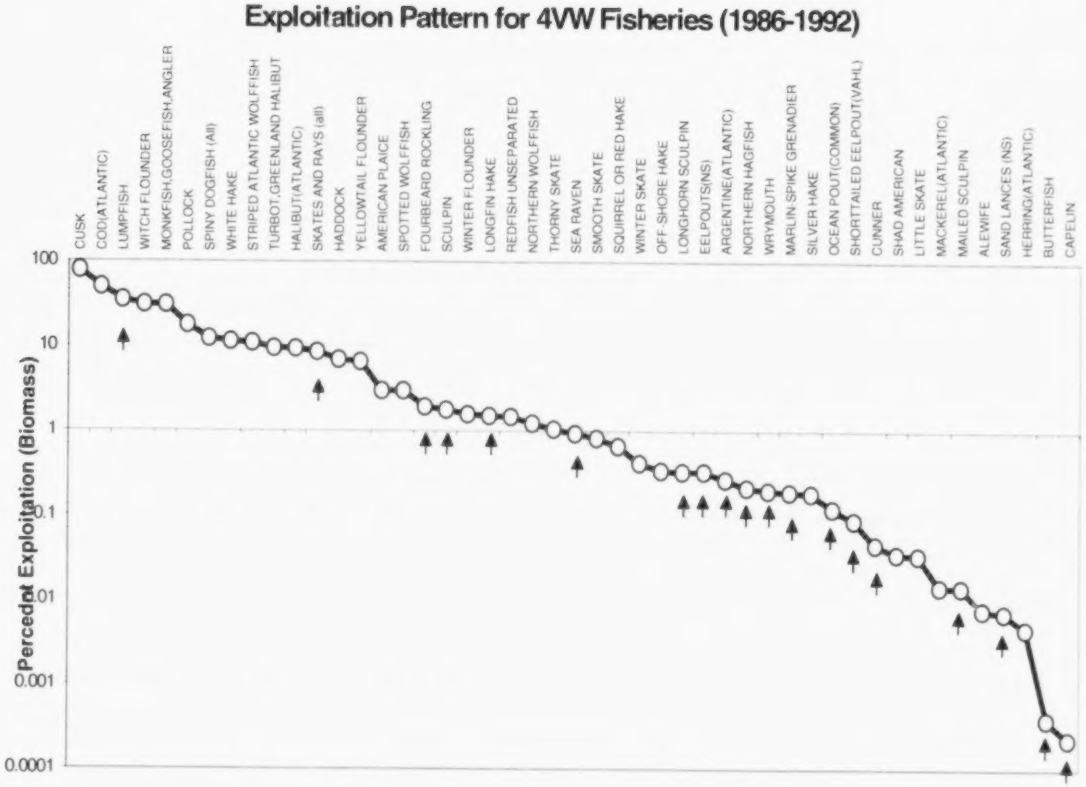


Figure 22. Nominal exploitation profile for the eastern Scotian Shelf by large trawlers fishing during the period 1986-1992. The exploitation profile is restricted to those fish species caught at rates greater than 1 per 100 sets and those for which q-corrected biomass estimates were available (arrows indicate non-commercial species).

One objective of managing the fishing activities of humans in these ecosystems should be to minimize the both the frequency, and the rate at which non-target, non-commercial fish (in this instance) are caught. The catch, and exploitation profiles for the fishery (or area) in question, will indicate whether or not our management measures are successful in achieving or moving toward this goal. To achieve this objective, catch profiles based on best available data, should be reported as a standard feature of all single species resource assessments. Fisheries management, as part of the regular fisheries statistics gathering process, could monitor these catch profiles and fisheries with excessively wide (many non-target species), or excessively deep (large quantities of specific non-target species) bycatch profiles, could be scrutinized and offered incentives for reducing the ecological footprints of their fisheries.

5.2.3 Outstanding Issues – Work Towards Ecological Profiles from Catch Profiles

Although the above analysis improves our overall view of the impacts of a specific fishery sector, it does not present a complete estimate of impacts of fishing on the Scotian Shelf. Neither is it an ecological profile for that fishing sector since it focuses solely on the exploitation in fish species space. To move, from these initial results, to a more comprehensive analysis that will culminate in the development of ecological profiles (really a form of full-cost-accounting) we must expand the current analysis to include:

1) Development of catch and exploitation profiles for the other fisheries for which we have on-board observer information, particularly smaller trawlers and longline gear.
2) Develop catch and exploitation profiles by fishery and area. From our initial analysis it is evident that trawlers and longliners have very different patterns and that these will vary by area. Such differential catch profiles might be used to devise an "ecological taxation scheme" as incentives for fishers to reduce overall ecological footprints of fisheries, by modifying gear and / or location of fisheries.
3) Develop catch profiles at spatial scales relevant to the distributional characteristics of impacted species. Some of the species caught have limited distributions and are therefore more vulnerable to over-exploitation.
4) Include impacts of finfish fisheries on invertebrate components of the ecosystem.
5) Include impacts of finfish and invertebrate fisheries on the physical structure of the ecosystem. Some of this work is already underway (Gordon, Gilkinson)
6) Develop a 'risk-assessment table' for all species for use as a screening tool for the species at risk legislation. This could be fishery and area specific to guide both listing and recovery planning efforts
7) Refine the catch and exploitation profiles to include size where feasible.
8) Include impacts not directly related to removal of fish or invertebrates such as pollution impacts of fisheries and impacts of offal, from, especially, shore-based processing plants.

5.3 IMPACTS OF FISHING GEAR

Human activities can have serious impacts on the structure, diversity and productivity of benthic habitat and communities. Within the ESSIM area, the fishing industry has the greatest impact at the present time. A wide variety of bottom-contacting fishing gears are used, including hydraulic clam dredges, otter trawls, scallop dredges, longlines, gillnets and pots. The impacts on benthic habitat and communities depend upon numerous factors, including the type of gear, how it is rigged, the intensity, frequency and distribution of its application, the type of benthic habitat and the kind of organisms present on the seafloor. There is extensive scientific literature on fishing gear impacts. Recent reviews of it include Chuenpagdee et al. (2003), Collie et al. (2000), Dayton et al. (2002), Johnson (2002), Kaiser et al. (2002), Kaiser. (2003), Morgan and Chuenpagdee (2003), National Research Council (2002) and Northeast Region Essential Fish Habitat Steering Committee (2002). DFO has conducted extensive research on the impacts of hydraulic clam dredges, otter trawls and scallop dredges on benthic habitats and communities common in Atlantic Canada.

There have been several recent attempts to rank the relative environmental impacts of different gear types. Chuenpagdee et al. (2003) assessed the collateral impacts of fishing gear used in US waters and came up with the following relative ranking from most to least damaging (on a scale of 100):

Bottom trawl	91
Bottom gillnet	73
Dredge	67
Midwater gillnet	63
Pots and traps	38
Pelagic longline	36
Bottom longline	30
Purse seine	4
Hook and line	4

The top four gears were considered to have high impact and warrant stringent policy in their use.

A similar ranking exercise was conducted by the Northeast Region Essential Fish Habitat Steering Committee (2002) for fishing gear commonly used in the northeastern US. The ranking of habitat impacts by gear type was very similar to that reported by Chuenpagdee et al. (2003):

Otter trawl	41
Scallop dredge	30
Clam dredge	7
Nets and lines	5
Pots and traps	1

A review of the extensive scientific literature reveals several generalities about the response of benthic habitat and communities to disturbance from different types of fishing gear. Those identified by NRC (2002) are:

- *Trawling and dredging reduce habitat complexity* - Direct effects include loss of erect and sessile epifauna, smoothing of bedforms, reduction of roughness, and removal of taxa that produce structure. If the interval between disturbances is shorter than the recovery time, benthic habitat and communities may not be able to recover to pre-disturbance conditions. Variable environments inhabited by short-lived species recover more rapidly than stable environments composed of sessile, long-lived species which sustain longer term damage.

- *Repeated trawling and dredging result in discernable changes in benthic communities* - Many studies report that repeated disturbance causes a shift from communities dominated by species with large body size to communities dominated by high abundance of small-bodied species. Intensively fished areas are likely to remain permanently altered and inhabited by species more adapted to frequent disturbance. The magnitude of these changes will depend upon the kind of habitat.

- *Bottom trawling reduces the productivity of benthic habitats* - There is evidence that benthic productivity tends to be lower in heavily fished areas compared to unfished areas. Impacts are cumulative and depend upon the frequency of disturbance. Repeated disturbance can exceed a threshold and can cause long-term effects. Small scale fishing disturbances can be masked by larger scale natural events. More long term studies are needed to assess the full range of consequences in areas disturbed regularly.

- *Fauna that live in low natural disturbance regimes are generally more vulnerable to fishing gear disturbance* - According to ecological disturbance theory, initial response and rate of recovery from disturbance should reflect the stability of the substrate in a particular habitat and the character of the benthic community it supports. Habitats consisting of unconsolidated sediments (e.g., sand) that experience high rates of natural disturbance can have more subtle responses than habitats characterized by pebbles or cobbles. Animals that live in unconsolidated sediments, in high natural disturbance regimes are adapted to periodic sediment resuspension and smothering, such as that caused by mobile bottom gear. In contrast, epifaunal communities that stabilize sediments, reef-forming species or fauna in habitats that experience low rates of natural disturbance, have been observed to be particularly vulnerable. Responses in sand habitats are generally less negative than in other habitats. Benthic fauna can be ranked according to their vulnerability, which can be predicted from the morphology and behaviour of individual species. Soft-bodied, erect, sessile epibenthic organisms appear to be the most vulnerable to fishing gear disturbance.

The review conducted by the Northeast Region Essential Fish Habitat Steering Committee (2002) also included a ranking of four different impacts on habitat type. These impacts were removal of major physical features, impacts to biological structure, impacts to physical structure and changes in benthic prey. The three general habitat types considered were mud, sand and gravel. Gravel habitat was clearly considered to be most at risk, followed by sand and mud. Impacts to biological structure were of greatest concern, particularly in gravel habitat, followed by any impacts to gravel habitat. Impacts to physical structure were ranked third and removal of major physical features ranked fourth. Otter trawls and scallop dredges were judged to have the greatest impacts on gravel habitat. Otter trawl impacts are of concern in all three habitat types, scallop dredge impacts are limited to gravel and sand habitats, and clam dredge impacts are limited to sand habitats. Bottom longlines are only of concern in gravel habitats. Similar rankings of habitat vulnerability have also been reported by Collie et al. (2000) and NRC (2002).

Since the impacts of different fishing gears clearly depend upon the type of habitat, it is important to develop a system for benthic habitat classification that can be used to map the amount and distribution of different components within a defined geographic area such as the eastern Scotian Shelf. Numerous different benthic habitat classification systems are available and are being considered, but for this application one based primarily on sediment grain size (i.e. mud, sand and gravel), seems most practical at this time. For example, using data from NRCan data bases, the grain size of surficial sediments has already been mapped for the entire Scotian Shelf (Kostylev 2004). The science of habitat characterization and classification is evolving rapidly and more sophisticated habitat mapping methods and products should be available within a few years.

Despite the lack of long-term data sets of benthic communities in Atlantic Canada, there is evidence that fishing gear has changed benthic habitat and communities under some conditions. For example, Kenchington (unpublished data) reports changes in the composition of benthic communities in scallop beds off Digby over a 30-year period. In addition, fishermen report widespread impacts observed during their long careers working at sea (Fuller and Cameron 1998).

While there may be debate about the extent and long-term implications of the impacts, there is no doubt that the use of hydraulic clam dredges, otter trawls, scallop dredges and bottom-tending longlines is affecting benthic habitat and communities within the ESSIM area. Therefore, it is important to take management action to protect the structure, diversity and productivity of benthic habitat and communities where needed.

5.4 OIL AND GAS EXPLORATION AND PRODUCTION

Oil and gas activity on the Scotian Shelf is one of the main non-fishing industrial activities taking place on the continental shelf and slope. Potential reserves, principally of natural gas, have been identified through exploration activity beginning in the 1960s. Although oil and gas related activities on the eastern Scotian Shelf are relatively modest in scope, compared with other areas of the world, exploration and production can lead to ecosystem impacts and conflicts with the fishing industry.

Potential impacts and conflicts include, influences of drilling wastes and produced water on local ecosystems, spawning and nursery areas, accidental spills of hydrocarbons and drilling fluids, both from production and operational wastes, on benthic or demersal resource species (e.g. scallops, groundfish), and exclusion zones and seabed structures interfering with fishing activities. Hydrocarbons produced to date on the shelf are either light (condensate) or natural gas, which tend not to have the same severity of impacts on ecosystems as crude oil.

Over 194 wells had been drilled in the ESSIM area (up to the end of 2002, Wildish and Stewart 2004), mostly concentrated in the Sable Island area but otherwise distributed broadly. Activity culminated with the first production (condensate west of Sable Island at Cohasset Panuke, in 1992-1999) and natural gas south of Sable Island in the Sable Offshore Energy Project (SOEP). The SOEP presently produces from five fields (CNSOPB 2005). Both the continental shelf and slope of the Scotian Shelf are considered potential targets for exploration. Exploration activity and interest is ongoing, located in both the ESSIM area and the western Scotian Slope. Two exploration wells were drilled in 2004. Seismic surveys have continued on the Scotian Shelf, and 15,771 kilometres of 2D and 4,026 square kilometres of 3D seismic data; and 514.2 kilometres of 2D data and 353.3 square kilometres of 3D data were acquired on the Scotian Shelf and slope in 2003 and 2004 respectively (CNSOPB 2005). Most of the recent (post 1984) seismic surveys have taken place on the mid- to outer Scotian Shelf and slope, and along, and extending into the Laurentian Channel. Early surveys (pre-1984) included nearshore areas in the Bay of Fundy, and around Cape Breton, including Sydney Bight, and extending into St. Georges Bay (CNSOPB Personal Communication). Seismic surveys have also been conducted in Sydney Bight in the summer of 2005. Effects of seismic activities on the lucrative snow crab fishery in the area is presently an issue.

Outside the ESSIM area, a drilling moratorium was instituted on Georges Bank in 1988 and renewed after an independent review in 2000. The crucial issue was the importance of the scallop stocks on the Bank and the potential of drilling wastes and accidental spills to damage the resource. Overviews of the issues and supporting knowledge are presented in Gordon (1988) and Boudreau et al. (1999).

5.4.1 Impacts of Drilling Wastes (Muds and Cuttings) on Benthos

(a) Suspended Particulates and Toxic Effects.

The main impacts of offshore oil and gas result from releases of drilling fluids and related materials, operational releases, produced water and accidental spills of drilling material or hydrocarbons (e.g. oil and diesel). In routine operations, offshore hydrocarbon exploration and development is responsible for a wide range of materials and contaminants entering the marine environment (GESAMP 1993). The principal materials released during exploration and development are drilling fluids, predominantly based on muds and weighting agents which lubricate the bit and drill stem, balance pressure, and bring cut rock (cuttings) to the surface for disposal. Different types of muds and lubricants are used at different stages of drilling (water-based in shallow drilling; oil-based for deeper portions of wells). Normal operations involve no bulk releases of drilling fluids to the ocean although some materials may enter as a coating on cuttings. The present situation is an improvement over practice in the early stages of hydrocarbon development on the Scotian Shelf where releases were the norm.

Much of the work on impacts of offshore hydrocarbon exploration and development has focused on drilling wastes, with a preponderance of studies in the North Sea but also including the Gulf of Mexico and coast of California, where significant hydrocarbon reserves have been exploited. In these areas over the lengthy period of production, the technology has evolved in response to environmental concerns. Less toxic drilling muds and fluids have been developed such as 'synthetic-based' muds (SABs) where the toxic effects from dissolved components have been largely removed, although the muds can still result in smothering and create some oxygen demand on the bottom (see below). There has also been a tendency, particularly on the Scotian Shelf, to avoid deposition of muds in the offshore and transport them to shore for disposal. Chronic toxicity of flounder and snow crab, and impacts on sediment communities (dose-response relationships in Microtox, polychaete and amphipod sediment bioassays) of ester-based (synthetic) and aliphatic based (conventional) fluids have been examined (Payne 2003). Views of the mode of interaction of drilling muds with the marine environment and sea floor life have also evolved. It is now recognized that discharged drilling muds flocculate (form aggregations, increasing particle size and settling rate), forming particles on the order of 0.5-1.5 mm in diameter, and behaving more like larger particles (Cranford, in press), can settle rapidly and accumulate on the seabed (Muschenheim et al. 1995; Muschenheim and Milligan 1996)

Early studies (Neff et al 1989) showed barite from drilling on Georges Bank at significant distances (up to 65 km) from drill sites and DFO studies found drilling mud in resusupended material from the benthic boundary layer at 8-10 km from the Cohasset near Sable Island. Modeling approaches to the dispersion of drilling muds near the seabed have been developed within DFO (benthic boundary layer transport model, bblt (Hannah 2005)) in relation to providing input to the Georges Bank moratorium process on the potential effects of drilling muds on the valuable Georges Bank scallop stocks. The bblt model was used to make mud dispersion predictions for the Sable Offshore Energy Project (SOEP), and for developments on the Grand Banks (Hannah and Drozdowski in press; Cranford in press).

Zones of influence in terms of detectable hydrocarbons from drilling activities in sediments have extended to several kilometres from active rigs (e.g. Olsgaard and Gray 1996), but are expected to be less in highly dispersive environments of the Scotian Shelf. Cohasset and Panuke monitoring found drilling mud hydrocarbons 250 m from the well site. An earlier study of bottom sediments at an exploratory well site (Carter et al. 1985), found a residual metal signature several years after drilling. EEM (Environmental Effects Monitoring) programs for development activities for the presently producing facilities include sediment monitoring but haven't been reviewed here. DFO is carrying out analysis of vibracore samples in the vicinity of SOEP facilities to determine the distribution of materials such as barite and bentonite (Muschenheim, pers. comm.).

Several strategic research initiatives were begun in the 1980s to address impacts of drilling wastes on offshore environments. Environment Canada sponsored toxicity assessments of oil-based drilling muds on fourth stage lobster larvae, arctic quahaugs, *Macoma balthica*, and sea urchin to assist in developing guidelines for drilling mud disposal (Hutcheson et al. 1987). In relation to providing science advice to the Georges Bank moratorium process, DFO carried out studies on impacts of drilling wastes on sea scallops (*Placopecten magellanicus*) and modeling approaches to the dispersion of drilling muds near the seabed were developed (Hannah et al. 1995; Tedford et al 2001; bblt Version 7m Drozdowski et al. 2004; Hanna and Drozdowski in press.). Bentonite clay and barite ($BaSO_4$) are the main components of drilling fluids, and previous studies, found that at relatively high concentrations (100-1000 mg/L) scallops were among the few sensitive species (Cranford in press). DFO's studies of both substances individually, as well as in combination with mineral oils, and under realistic concentrations and flow regimes, gave definitive indications of chronic effects of various compounds, and sometimes acute effects at low concentrations (Cranford in press; e.g. Cranford and Gordon 1991, 1992).

In response to laboratory observations of the high sensitivity of sea scallop growth and physiological responses to very dilute concentrations of operational drilling wastes two biological effects monitoring tools were developed using scallops as sentinel organisms (Cranford in press) and tested at the Hibernia oil production site. The first approach is based on the *in situ* sediment trap method of Cranford and Hargrave (1994) monitors feeding and digestion responses of bivalve filter feeders *in situ*. This system (HABITRAP) showed that drilling wastes (barium) were only in suspension for a brief period during the study and that concentrations were below the threshold known to impact feeding and growth rates. A second technique consists of a series of *in situ* moorings containing caged Iceland scallop, sea scallop and blue mussel deployed near an operating production platform. A test deployment near Hibernia showed no significant difference in mean tissue dry weight (gonad, adductor, digestive, and total) between the six sites at the end of the three-month deployment.

(b) Smothering

Smothering is an obvious result of deposition of large quantities of drill wastes over short time periods, but is a minor issue under current management regimes, where planned dumping of wastes (e.g. drilling muds) is relatively less common. Cuttings released into the ocean can create piles on the seabed and smother organisms underneath. Synthetic-based drilling muds, although containing low toxicity oils, may have an oxygen demand which also leads to reduction in oxygen levels beneath the seabed, however, this is not a major issue. Drill wastes and cuttings disperse with time.

(c) Tainting

Tainting of fish and shellfish has been a concern, with offshore oil and gas development, but has not been a problem. Ernst et al. (1989) have shown potential tainting of cod from crude oil. Monitoring for the Cohasset and Panuke sites included *in situ* moorings of blue mussels in the vicinity of the platforms during development drilling (July-November 1993) and both taste tests (organoleptic) and chemical analysis of tissues (Parsons and Associates 1996; Zhou et al. 1996) were performed after two months of exposure. Hydrocarbons from oil-based drilling muds in tissues were found as far as 10 km from the site and as far as 20 m off the bottom at 10 km. Tainting, however, was detected only within 500 m of the wellsite during active drilling and was not detected within a few months of cessation of drilling (Parsons and Associates 1996). Tainting and depuration studies in snow crab in connection with synthetic-based muds have also been carried out (Payne 2003).

(d) Impacts on biodiversity

The impacts of oil and gas on biodiversity on the eastern Scotian Shelf have not been studied. Wellsite monitoring studies and DFO studies to sample in the vicinity of operating platforms (e.g. Cohasset Panuke) have not focused on discriminating changes in benthic communities. Based on studies from other areas of the world, it is likely that zones of impact would occur, although the impact may be reduced compared to other less dispersive environments. Due to the relatively small proportion of the ESSIM area affected by oil and gas exploration and development, oil and gas exploration will likely not result in significant overall loss of biodiversity.

Deepwater corals have become a biodiversity conservation concern, but there is no information on the impacts of offshore oil exploration and development on them. *In situ* studies in shallow water showed no effect (Hudson et al. 1982) but laboratory exposures have demonstrated effects, including burial, behavioural changes, and mortality, under different conditions (Thompson and Bright 1980; Dodge and Szmant-Froelich 1985; Dodge 1982)

(e) Seabed Heating

Buried flow lines associated with the Sable Offshore Energy Project have been reported to heat the seabed (Muschenheim, personal communication). Heating could accelerate biological processes and potentially lead to reductions in dissolved oxygen in these areas, but there have been no studies conducted to determine the magnitude of any impact

(f) Miscellaneous Releases

Accidental releases of fluids and other substances related to oil and gas exploration and production have been reported worldwide, and on the Scotian Shelf. Major reference works and symposia include the US National Research Council (1985) volume on hydrocarbons in the marine environment; offshore oil and gas development (Boesch and Rabelais 1987; Englehardt et al.1989) and produced water effects (Ray and Englehardt 1992; Reed and Johnson 1996); environmental effects focused on the Scotian Shelf (Gordon et al. 2000) and environmental effects monitoring (Armsworthy *et al.* 2005).

5.4.2 Impacts of Structures

(a) Impacts of exploration drilling rigs and associated structures

Movement of rigs between areas of the world's oceans can potentially introduce marine invasive species, in particular during visits of rigs to coastal ports. There have been no studies or evidence of occurrences of invasive species, by this means, on the Scotian Shelf.

Rigs can result in localised seabed disturbance through placement of anchors and chains, placement of legs (jack-up rigs), disturbance of the surface sediments during operations, excavation of well pits, and installation of seabed equipment (e.g. blowout preventers). Scour can take place around bases of legs.

(b) Impacts of production platforms and associated structures

Generally, impacts on the local marine environment have not been considered in studies of impacts of offshore development. A review conducted for SOEP (CORDaH Management Consultants, Aberdeen, UK, 1997) found no studies to suggest either a positive or negative effect from fouling.

Marine growth is typically an operational issue with respect to increased hydrodynamic loading, static loading, corrosion, and blockage of water intakes. Structures (including rigs, wellheads, pipelines, anchors, anchor lines etc.) provide additional surface for colonization of organisms (plants and animals) forming local hard-substrate ecosystems (e.g. Wolfson et al 1979). A substantial body of literature is available concerning artificial reefs (e.g. rock reefs, artificial concrete structures, abandoned oil rigs, anchor buoys etc.) designed to enhance marine communities, principally fisheries. Fouling is overwhelmingly considered a positive attribute of marine structures (e.g. see Bohnsack and Sutherland (1985), Pratt (1994))

Operators on the Scotian Shelf monitor marine fouling on exploration and development structures where fouling growth can reach critical levels within a year or two of installation. As an example, at the Cohasset Panuke site, the operator pursued an integrated biofouling management program through the life of the development. Some built in features were included (e.g. marine growth preventors, brushes which move with the waves to clean tubular structures). Types of organisms on the Cohasset Panuke structures were common to Nova Scotia coastal waters and exhibited significant temporal and spatial variability typical of biofouling communities (SOEP Submission to Joint Panel Review, Appendix 1 – I.R. 2.9). Species include algae (*Enteromorpha, Ulva, Porphyra, Polysiphonia, Desmarestia, Dictyosiphon, Alaria, Chorda tomentosa, Laminaria digitata*) and animals (sea anemones, sea squirts, horse mussels, blue mussels, seastars, barnacles, bryozoa, hydroid polyps, tube worms and sponges). Communities exhibited zonation with highest development of seaweeds and associated organisms in the upper 15 metres. By far the most abundant organisms were mussels, hydroids (*Tubularia* sp), and seaweeds.

In some cases, habitat is also affected around offshore structures and artificial reefs. Marine growth on offshore structures can result in changes in particle size and composition of sediments around rigs, due to materials such as carbonate shells from attached organisms, such as mussels and barnacles. The Pendleton artificial reef in California (Ambrose and Anderson 1990) resulted in the development of coarser grain size in sediments near the artificial reefs. An effect on abundance of several polychaete species was also noted, due to the physical (hydrodynamic) presence of the reef, but also due to the presence of shelly debris. In contrast, around the Cohasset site, routine surveys over six years suggested that mussel shells didn't accumulate on the seabed.

Benthic macro and meiofaunal communities around rigs display changes relating to organic enrichment (from sloughed off primary and secondary productivity from the structure), contamination by toxicants (e.g. heavy metals and hydrocarbons), and changes in sediment grain size away from offshore production platforms (Montagna and Harper 1996). Some fish species may be enhanced around platforms (Ellis et al 1996). Fish which associate with reefs or platforms may also cause predation pressure in the vicinity of offshore structures.

(c) Impacts of pipelines

Exposed pipelines are an obstacle for animals moving along the seabed but are generally not a significant barrier. Video surveys of the Sable Island pipeline show that it is commonly occupied by megafauna such as crabs (Martec et al. 2005). Burial of pipelines temporarily disrupts the seabed which subsequently recolonizes with benthic organisms. Hard bottom was disrupted by pipeline burial in the inshore portion of the pipeline at the landfall but was recolonized rapidly with seaweeds (SOEI Submissions to Review Panel, 1998-2000).

5.4.3 Impacts of Petroleum Spills and Blowouts

The only hydrocarbons currently produced on the Scotian Shelf to date are natural gas and condensate, a light, highly volatile hydrocarbon. Both have reduced (though not insignificant) impacts compared with heavy hydrocarbons such as crude oil, through their high volatility. Accidental releases of hydrocarbons and drilling fluids can occur, through facilities malfunction and spills during fluids transfer (e.g. diesel fuel; drilling muds transfer); or blowouts. A major blow-out of the Uniacke G-72 occurred during exploration on the Scotian Shelf releasing 1,500 barrels of condensate into the ocean near Sable Island in 1984. Spills from supply vessels frequently involve diesel oil which is highly toxic, in particular having high contents of polycyclic aromatic hydrocarbons (PAHs) and potential to harm seabirds, but spills of lubricating and hydraulic oils can also have severe impacts.

No impacts on benthic organisms have been documented in relation to spills or blowouts in the Nova Scotia offshore.

5.4.4 Impacts of Produced Water

Produced water is a brine that is extracted from rock formations. It is the main release during hydrocarbon production, principally occurring in crude oil production, and increases in volume released over the production phase, in some cases exceeding the volume of hydrocarbon production of an oil field by an order of magnitude. It contains components of concern, including hydrocarbons (dispersed and dissolved), trace metals, nutrients, particulates (mud, sand), radioactive elements (Naturally Occurring Radioactive Materials—NORM including dissolved ^{226}Radium and ^{228}Radium and low levels of ^{210}Pb), organic compounds such as phenols and fatty acids, and brine. Produced water also varies greatly in composition between fields. Produced water is normally processed to remove hydrocarbons before release, but still contains residual hydrocarbons at low levels. About 10% of the oil released in the UK offshore comes from produced water (Davies et al. 1989). Processes acting on produced water include dilution, volatilization, chemical reactions, adsorption on suspended solids, and biodegradation. Flocculation processes, when the produced water enters the ocean, lead to metal-rich particle flocs, which settle to the seabed. Once on the seabed they lead to potential exposure of benthic communities and resource species (Lee *et al.* 2005; Querbach *et al.* 2005; Cranford *et al.*1998). Chemical processes operating when produced water mixes with seawater, can also alter (reduce) its toxicity with time (Lee et al. 2005). Work on produced water effects has been carried out using brine shrimp nauplii, and *Calanus finmarchicus*, showing low acute toxicity (Payne *et al.* 2001, Lee et al. 2005).

Produced water can have chronic toxic effects (e.g. effects on larvae and growth of adult bivalves) on organisms within a few hundred metres of the release point (Schiff et al 1992; Raimondi and Schmitt 1992; Din and Abu 1992; Booman and Føyn 1996; Krause et al. 1992) and can affect benthic communities (Mulino et al. 1996; Osenberg et al. 1992). Early developmental stages of important resource species (haddock, lobster and sea scallop) on the Scotian Shelf are more sensitive than other stages or phytoplankton, to exposures to produced water from the Cohasset Panuke production site (Querbach et al. 2005; Cranford et al. 1998). Toxic effects were observed at relatively high concentrations of produced water (typically greater than 1% for an LC_{50}). Components of produced water can accumulate in marine animals (Neff and Sauer 1996).

A general conclusion is that there would be only limited potential for acute toxicity beyond the immediate vicinity of rig sites in Atlantic Canada due to rapid dispersion, and limited volumes released during the present early development of hydrocarbon resources on the Scotian Shelf.

5.4.5 Impacts of Noise

(a) Seismic (2D, 3D, VSP)

Environmental assessments of the impacts of seismic surveys are a comparatively recent development in the Nova Scotia offshore, and were not required under the Canadian Environmental Assessment Act prior to 2003. Effects of seismic surveys are now routinely assessed, although the effects on vertebrates (e.g. marine mammals, sea turtles) are the prime consideration. The CNSOPB supported a class assessment of seismic activities on the Scotian Shelf in 1997-98 (Davis et al. 1998).

Current concern relates to seismic effects on, endangered whale species (particularly the northern bottlenose whale), and on benthic resource species (e.g. snow crab, lobster) and demersal fish (e.g. cod, haddock). A recent DFO synthesis of research on impacts of seismic energy on invertebrates indicated that seismic surveys with routine mitigation measures in place are unlikely to pose high risk of mortality of marine organisms (DFO 2004a). Results of an LGL study of seismic impacts on snow crab (Christian et al 2003) suggested no obvious effects on adult crab behaviour, health or catch rates. Another study of snow crab effects led by DFO and Corridor Resources, a proponent of a seismic survey off western Cape Breton, concluded that the survey didn't cause acute or mid-term crab mortality or changes in feeding behaviour, and that embryo survival and locomotion of the resulting larvae after hatch were unaffected (DFO 2004a).

(b) Drilling and Production

Noise from exploratory drilling has not been considered a significant issue in relation to benthic communities.

(c) Pipelines and Gathering Lines

Pipelines also generate sound and an electromagnetic field (Martec et al. 2004). A study of sound generated by pipelines on lobster behaviour in July and November 2003 showed peaks of low frequency sound (tonals) that are within the hearing range of lobster, in the vicinity of the Sable Island pipeline near its landfall (Martec et al 2004). These tonals were measured up to at least 200 m on both sides of the pipeline. The pipeline was shown to create a narrow magnetic field (two to three metres wide on either side) and up to one third as strong as that of the earth's background magnetic field. A lobster "catch and release" study program showed no statistically significant variation of catches between the pipeline locale and two reference sites.

5.4.6 Impacts of Lights and Flares

Lights and flares would not result in a significant impact on benthic communities because of the low intensity and attenuation of light by seawater.

Appendix 1 provides a listing of the work related to oil and gas issues for the Scotian Shelf that have been undertaken to date, while Appendix 2 gives an overview of the science required to support oil and gas impact initiatives.

5.5 MARINE ENVIRONMENTAL QUALITIES AND THE ECOSYSTEM

Marine environmental quality (MEQ), sometimes referred to as health of the oceans (HOTO), has been defined in a number of different ways. The Global Ocean Observing System Health of the Oceans Panel defined HOTO "*as the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, in particular habitat destruction, changed sedimentation rates and the mobilization of contaminants*" (IOC, 1996); Vandermeulen and Cobb (2004) state that MEQ "*objectives describe a desired physical, chemical or biological condition of the marine ecosystem*"; a DFO website says that MEQ relates to activities that "affect the physics, water chemistry and biology of marine ecosystems". Taken together, these definitions describe the 'quality' of marine biota (are they contaminated with chemicals? are they healthy?) and the physical and chemical quality of ocean habitats (both ocean waters and bottom sediments), especially as all of these attributes are impacted by human activities. The direct impacts of human activities may be physical (e.g., disruption of bottom habitat by bottom trawling or oil/gas pipelines; smothering of benthic communities by suspended matter discharges from oil well drilling or marine mining), chemical contamination from various sources (e.g., produced water from oil platforms; marine dumps of chemical munitions) or biological (e.g., pathogenic contamination of organisms; introduction of exotic species).

The sources of threats to MEQ resulting from human activities are relatively easier to identify in an offshore environment like the ESSIM area than in nearshore waters. Clearly, the direct and indirect impacts of fishing are the most significant human impacts on the ESS. In addition, despite its remoteness, the ESS is not immune to the effects of chemical contaminants. Distant sources of contaminants include contaminants transported through the atmosphere and by the discharge of the St. Lawrence River through the Gulf of St. Lawrence. Figure 23 clearly shows that copper levels in waters of the ESS, where the influence of the St. Lawrence discharge is highest, are higher than those elsewhere on the Shelf. Copper is of particular concern, because the natural concentration of copper in seawater is already close to those known to have impacts on marine organisms, especially primary producers (Fitzwater et al. 1982; Moffett and Brand, 1996). Any additional anthropogenic copper, either from distant or local sources, could alter the phytoplankton community.

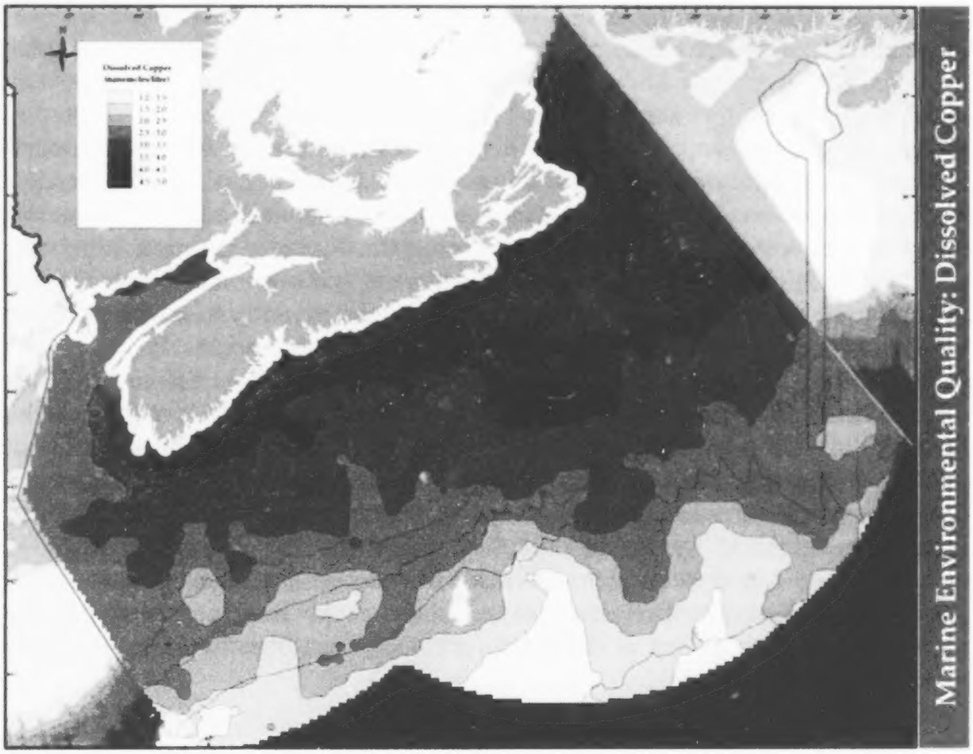


Figure 23. Copper in surface waters of the Scotian Shelf.

Contaminants, from oil and gas exploration and development physically disturb the seabed near drilling platforms, and can contribute substantial amounts of chemical contaminants, including hydrocarbons, heavy metals and nutrients from produced waters, to both the water column and the seabed. Estimates of the amounts of contaminants discharged in produced water, from production platforms near Sable Island (SOEP, 1996), suggested that the quantities of some contaminants were very large, perhaps even comparable to the total discharge for some contaminants from the St. Lawrence River discharge. Oil and gas activities also affect the acoustic environment of the ecosystem (see section on oil and gas above).

Other human activities that can impact MEQ on the ESS include physical disruptions to the seabed during the laying and maintenance of telecommunications cables, chemical contamination from military dump sites, discharges from shipping (including leaching of antifouling agents from hulls), and the introduction of bioinvasive species from ships.

The purpose of setting MEQ objectives and doing MEQ monitoring is to protect both the quality of marine biota and the capacity of marine habitats to support life from the impacts of human activities. The selection of suitable indicators to measure MEQ is essential for successful implementation of MEQ objectives. Detecting severe impacts can be accomplished through observations of the ultimate biological responses, such as gross changes or elimination of a local marine community; or through observations of the presence of causative agents, such as drill cuttings on the seabed or high concentrations of chemical contaminants in surface sediments. Detection of severe impacts is not particularly dependent on the choice of indicator. Selecting suitable indicators and defining MEQ objectives capable of providing early warning of environmental degradation and protecting against more subtle impacts, is much more problematic.

To illustrate this point, consider the case of chemical contamination of sediments, which occurs on the Scotian Shelf in response to both local and distant sources. It is relatively straightforward to measure concentrations of specific contaminants in the sediments. But to assess the severity of the threat to the ecosystem, the connection between the degree of chemical contamination and the severity of the biological impact must be known. A great deal of effort has gone into one approach to establishing this connection by comparing toxicity test data with levels of contaminants in sediments. The Canadian Council of Ministers of the Environment (CCME, 1999-2001) has derived Threshold Effects Levels (TELs) and Probable Effects Levels (PELs) for a number of chemicals. These levels correspond approximately to the levels at which sensitive organisms start to show a response and levels at which there is a high probability of toxic effects, respectively. The application of these guidelines is complicated by the need to adjust the guidelines for natural variations in background levels, and the unknown degree to which the toxic responses exhibited by these individual organisms are indicative of broader scale community, population, or ecosystem effects. Having said all this, the sediment quality guidelines are exceptional in that actual numerical thresholds have been derived using a well documented process, a goal that is desired for all ecosystem objectives, but is frequently not obtainable with present knowledge.

It is also possible to use toxicity measurements as indicators of sediment MEQ. Such measurements are more closely tied to biological impacts, but the results are subject to more uncertainty in interpretation than measurements of contaminant concentrations. The interpretation of the results is further complicated by the absence of generally accepted thresholds suitable for use in assessing MEQ and the uncertain relevance of these toxic responses to ecosystem impacts.

Direct measurements can also be made on attributes of populations, communities or of the whole ecosystem. For example, measurements of total biomass, species richness or biodiversity, and community metabolism are possible indicators for the MEQ of benthic environments. However, such measurements are not straightforward, and they must be interpreted within the context of a large natural variability in time and space of both the property being measured and the nature of the benthic habitat.

As indicators move from those based on the direct threat (chemical concentrations), to responses of individual organisms, to community /population /ecosystem effects, the connection between the measurements and the ecosystem properties that managers wish to preserve becomes more closely linked, but the difficulties in making and interpreting the measurements become more severe. Recognition of these trends have led to the concept of the 'Sediment Quality Triad', which is a combination of all three types of measurements proposed as a tool for thorough MEQ assessments (e.g., Chapman et al. 1997). But such comprehensive measurements may be too resource hungry for implementation on a wide scale: the value of the simpler chemical measures as a screening tool has been recognized in some large scale MEQ assessments (e.g., Kiddon et al. 2003).

The trends described here for chemical contamination of sediments is a general one in marine MEQ. For example, mapping the area of the seabed disturbed by bottom trawling is easier than assessing the impact on local organisms which in turn is easier than assessing the ecological significance of the disruption. Recent studies on the physical impacts of fishing on benthic habitat on both the Grand Banks and Scotian Shelf (e.g., Gordon et al., 2002) have established some important relationships between fishing and impacts on the local communities, but the selection of practical indicators and thresholds will still rely heavily on expert opinion until a better understanding of the ecological significance of such local impacts is available. Similarly, the link between stressors and individual organisms has been examined in studies of the impacts of offshore drilling wastes on scallop growth rates (Cranford et al., 1999). This work has been extended to a larger scale by combining a physical model of the dispersion of the wastes with the growth rate response (Cranford et al. 2003). This groundwork certainly would make scallop growth rates a potentially useful indicator, but the overall ecological significance of such growth rate measurements is not known at this time.

Adaptive management and reliance on expert opinion, or even best scientific guesstimates, will be a feature of MEQ aspects of integrated management for the foreseeable future. As further research is done, better indicators and more soundly based threshold values will undoubtedly emerge. The challenge for managers will be to develop management approaches that are sufficiently flexible to recognize the uncertainties in the underlying science and to incorporate new scientific information quickly as it becomes available.

6.0 INTEGRATING CONCEPTS

Ecosystems are complex 3-dimensional systems that are subject to both internal controls and external forcing factors such as temperature. Species within these systems are linked through an array of trophic and competitive interactions, which can have direct and indirect effects. Marine ecosystems typically span 5 trophic levels ranging from primary producers and grazers to upper level predators and include detrital and other feedback loops. Understanding the complexity of marine ecosystems is an ongoing process through both descriptive and modelling approaches. We have a good understanding of some of the constituent parts of the eastern Scotian Shelf ecosystem, but our understanding of how these work together as a whole, that is, of the ecosystem dynamics and their response to environmental change is less good. However, several recent studies have furthered our knowledge of the dynamics of the eastern Scotian Shelf ecosystem. These studies begin from the precept of studying the ecosystem has a whole.

6.1 BIODIVERSITY

Biodiversity, that is the species richness and composition of any given marine ecosystem, relates to both the productivity and stability of that ecosystem. Changes in biodiversity, manifested either as reduced species richness or changes in the proportional composition of the component species, can result in complex reorganizations of such ecosystems. Such reorganizations exhibit changes in production and stability, and are mediated through changes in trophic interactions that can result in trophic cascades and shifts to undesirable (from some human perspectives) states of the ecosystem (see below). These reorganizations in turn result in changes in the richness and particular species composition of the reorganized ecosystem. The feedback mechanisms initiated by changes in biodiversity can cause further changes in biodiversity. The specific mechanisms responsible for such reorganizations of ecosystems are poorly understood. To fill these gaps in knowledge and to foster ecosystem-based management of human activities in marine systems, it is essential that we increase support for studies linking biodiversity (and changes to biodiversity) to changes in trophic interactions (productivity) and spatial and temporal stability. Without such knowledge, and given the relatively non-selective impacts of most human activities on biodiversity (e.g., fisheries bycatch of a broad array and high biomass of non-target species), it will be challenging to achieve one of the primary ecosystem-based fisheries management goals, namely minimizing the risk of irreversible change to natural assemblages of species and ecosystem processes.

There is an array of conservation objectives that relate to the general category of biodiversity; these operate at three levels of biological organization (community, species, and populations). It is apparent that our current understanding, of how the biological diversity of any particular piece of ocean is established or maintained, is rudimentary. We have some understanding of how population numbers or, biomass, of individual species (mainly fish and some larger invertebrates) have responded (or at least changed) over time and space, but we have not been successful in definitively attributing these changes to specific causes (see discussion of fishing effort and changes in biomass, and size structure above). Given this uncertainty, and the obvious and deleterious changes that have occurred in this and other marine ecosystems, it is essential that we adopt a highly precautionary approach that ensures that enough "real estate" will be conserved to achieve the overarching objectives referred to in § 2.2.

We have identified a number of objectives that relate directly to the conservation of communities within the bounds of natural variability. We define this variability in a multi-dimensional sense in that it encompasses geographic extent and location, three-dimensional structure (both physical and biogenic), species composition (relative species proportions), and species abundance. These objectives are to conserve

i. Diverse seascapes
ii. Distinct hotspots
iii. Communities susceptible to disturbance, specifically coral and other fragile benthic communities
iv. Highly diverse benthic communities
v. Pelagic communities and assemblages - The fisheries independent surveys have generally focussed on demersal and semi-pelagic species and have provided only rudimentary information on the (fish) species composition and dynamics of these communities over

the past 35 years. Synoptic information on other biotic components of pelagic communities is equally sparse. This indicates that the definition of these communities will be a significant initial challenge.

vi. Seabird communities

There are a number of initiatives that will inform the conservation objectives under this heading, including the work on benthic habitat classification (§ 4.3). There are some indications that this approach will allow us to classify the entire Shelf and thereby inform the process of choosing areas that will be slow or unlikely to recover from disturbances as opposed to those which are likely to recover quickly. If successful this would allow us to predict where fragile communities are likely to be found in addition to the ones already specifically identified under objective (iii) above. This initiative has also compiled the information required to test Huston's (1979) hypothesis that biodiversity is controlled by the interaction of productivity and disturbance. This could lead to a classification of the Shelf in terms of an area's potential diversity. If successful this would allow us to predict where the "hotspots" and highly diverse benthic communities are likely to be found and would greatly reduce the cost of surveying to find them.

We have also identified a conservation objective that relates to the prevention of invasive species. Although our current understanding of the diversity of particular taxa (i.e., fishes and macro invertebrates) would allow us to identify invasive species, for many other taxa our knowledge of species composition remains incomplete and would need to be enhanced so that invaders could be identified.

6.2 TROPHIC INTERACTIONS

We noted above that species are linked through trophic interactions. The nature of the control of these interactions has been an important question in ecology for some time (Hunter and Price 1992), that is, the relative influence of top-down versus bottom-up control of ecosystem structure and functioning. In the top-down view, consumers control the abundance and diversity of species at lower levels, whereas, in the bottom-up view, consumers are limited by the availability of food from lower trophic levels. Of course without primary producers, higher-level consumers could not exist. In this sense all ecosystems are under bottom–up control. In a foodweb solely under bottom-up control some combination of abundance and biomass should decline at progressively higher trophic levels for the simple reason that neither materials nor energy are perfectly conserved as they pass from prey to consumer. In contrast, food webs under strong top-down control with three or more trophic levels should display more of a constricted or oscillating trophic structure. For this reason top-down food webs are shorter than those under bottom-up control.

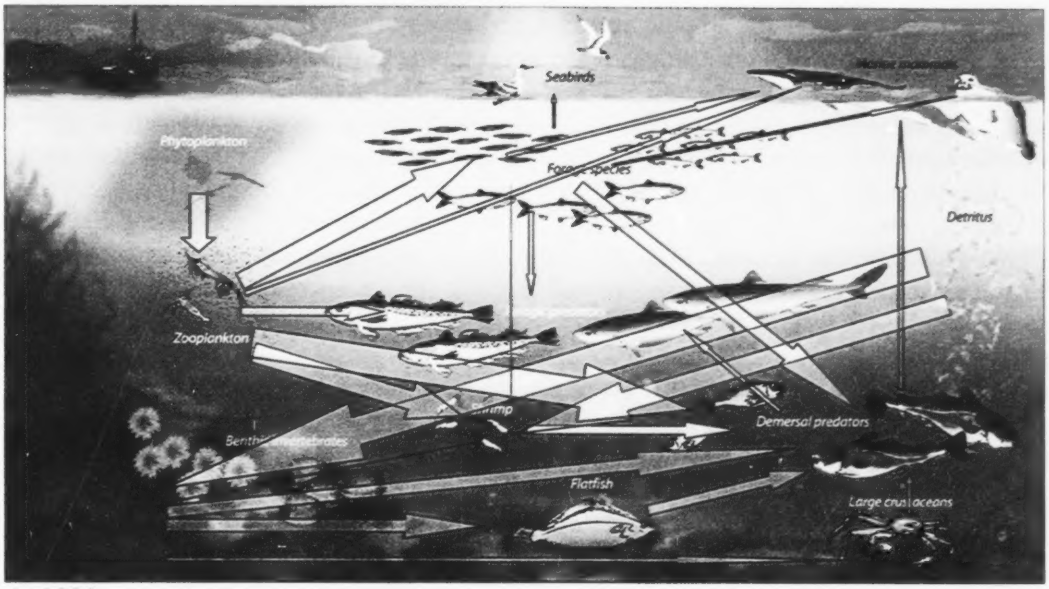
One of the stated objectives of ecosystem-based management within Canada is to maintain each of the biotic components of the ecosystem so that it can continue to fulfill its historic role in the foodweb, that is, to maintain its role in the trophic structure of the ecosystem. Currently our understanding of the specific trophic roles of all but a few species within the Eastern Scotian Shelf system remains rudimentary, although research such as the ecosystem modelling described next is making important contributions to this knowledge.

6.3 ECOSYSTEM STRUCTURE AND DYNAMICS

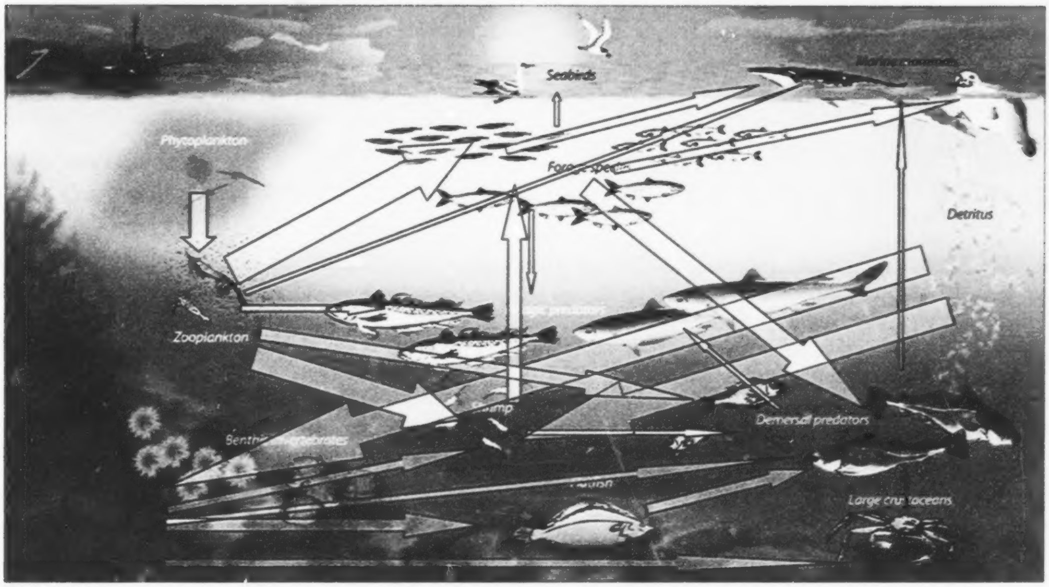
We have described the changes in the physical environment, the biological environment, and in fishing effort that have occurred on the Scotian Shelf over the past 3 to 4 decades and we have observed concomitant changes in the abundance and distribution of many marine species on the Scotian Shelf. Some demersal fish populations have declined precipitously and others have collapsed completely. This is particularly true of the commercially exploited species. We have shown that these changes have been most dramatic on the Eastern Scotian Shelf. At the same time, the abundance of other species, both invertebrates and small pelagic fishes, has increased (see Section 3 on Fish Communities above). These changes suggest that the trophic structure of these ecosystems has been altered. Disentangling the fishery and environmental effects leading to ecosystem change has, so far, been inconclusive. Multidisciplinary and ecological approaches are required, to better understand the changes that have occurred in the Scotian Shelf ecosystems.

Ecopath models have been developed for the eastern Scotian Shelf for two time periods: the early 1980s when the fish stocks had recovered from an earlier decline and were abundant and the 1990s when the groundfish stocks collapsed (Bundy 2004, Bundy 2005). The models encompass the decadal changes that have occurred in the eastern Scotian Shelf ecosystem and were used in a comparative way to understand the ecosystem in terms of productivity and biomass, trophic structure and changes in energy pathways. The models encompass the whole biotic system from primary productivity to top predators such as marine mammals.

The main trophic relationships that occur in the eastern Scotian Shelf ecosystem are depicted schematically in Figure 24a for the 1980s and Figure 24b for the 1990s. There are two main pathways, benthic and pelagic. At the base of the pelagic pathways are zooplanktons, which are an important food source for many marine species, including benthic species such as cod and other groundfish at larval and juvenile stages. One of the main pelagic pathways is zooplankton to forage fish to demersal predators. At the base of the benthic food chain is detritus, organic waste that is generated by living species through the water column which eventually descends to the benthos. Top predators in the systems include cetaceans and grey seals. In reality, feeding ecology is far more complex than suggested by Figure 24, as we will see below.



A. 1980s



B. 1990s

Figure 24. Schematic flow diagram for the eastern Scotian Shelf ecosystem depicting the main pelagic (green arrows) and benthic (blue arrows) pathways derived from Ecopath models for the 1980s (A) and 1990s (B). Width of arrows corresponds to the strength of the flow (Background figure, St. Lawrence Observatory Internet Portal - Dept. Fisheries and Oceans Canada http://www.osl.gc.ca.

A comparison of the two Ecopath models indicated that although total productivity and total biomass of the ecosystem remained similar between the early 1980s and late 1990s, there were changes in predator structure, trophic structure and energy flow, many of which were robust to uncertainty. There was a significant decrease in the biomass of demersal groundfish species and a significant increase in biomass of grey seals, small pelagic species, commercial crustaceans, zooplankton and phytoplankton (Table 6). The greatest change in the ecosystem is the switch from a demersal dominated system to a pelagic dominated system (the P:D ratio increased from 0.3 to 3.0.) indicating a shift in trophic flow from the demersal to the pelagic side of the food web. The P:D ratio is an indicator of the negative effects of fishing (Zwanenburg 2000; Rochet and Trenkel 2003). The rationale is that as longer-lived large demersal predators are removed by fishing, the abundance of small, short-lived pelagic species increase, due to a release from predation pressure.

Table 6. Comparison of biomass (t km^{-2}) of functional groups in early 1980s and late 1990s. Asterisks indicate that the differences between the two periods were significant, according to the Mann-Whitney U test (from Bundy 2005).

Functional Group*	early 1980s	late 1990s	% change	Mann-Whitney U test
Cetaceans and birds	0.24	0.27	13	
Grey seals	0.03	0.14	468	***
Demersal fish	13.33	7.72	-42	***
Pelagic fish	3.62	23.28	544	***
Commercial crustaceans	4.60	17.66	284	***
Other invertebrates	138.56	138.43	-0	
Zooplankton	50.13	78.58	57	***
Phytoplankton	34.38	43.56	27	***
Total	244.89	309.65	26	***

*Demersal Fish = Cod (*Gadus morhua*), Silver hake (*Merluccius bilinearis*) Haddock (*Melanogrammus aeglefinus*), American plaice (*Hippoglossoides platessiodes*), Halibut (*Hippoglossus hippoglossus, Reinhartius hippoglossoides*), Flounders (Pleuronectidae), Skates (*Raja sp.*), Dogfish (*Squalus acanthus*), Redfish (*Sebastes sp.*), Pollock (*Pollachius virens*), Demersal Piscivores, Large Demersals, Small Demersals. Pelagic Fish = Transient Mackerel, Capelin (*Mallotus villotus*), Sand lance (*Ammodytes dubius*), Transient Pelagics (*Scomber scombrus*), Small Pelagics (e.g., herring, *Clupea harengus harengus*), Small Mesopelagics. Commercial crustaceans = Shrimp (*Pandalus sp.*), Crabs (e.g., snow crab *Chionoecetes opilio*). Other invertebrates = Squids (*Illex illecebrosus, Loligo pealei*), Echinoderms, Polychaetes, Bivalve Molluscs, Other Benthic Invertebrates.

Biomass at all trophic levels increased significantly (Figure 25), and the composition of these trophic levels changed. The biomass increase at trophic level 4 was due to the increase in grey seal abundance and an increase in the number of other functional groups feeding at trophic level 4. In the early 1980s model, trophic level 4 was composed of four groups: transient pelagics, demersal piscivores, grey seals and large halibut (*Hippoglossus hippoglossus*). In the late 1990s model, it was composed of eight groups with the addition of small demersal piscivores, dogfish (*Squalus acanthus*), small halibut, and large cod (*Gadus morhua*). The total number of groups at trophic level 3 decreased by four, and the increase in biomass at this trophic level was due to the increase in biomass of forage fish species. The increase in biomass at trophic level 2 was due to the increase in shrimp (*Pandalus* sp.) and large zooplankton species (but see below).

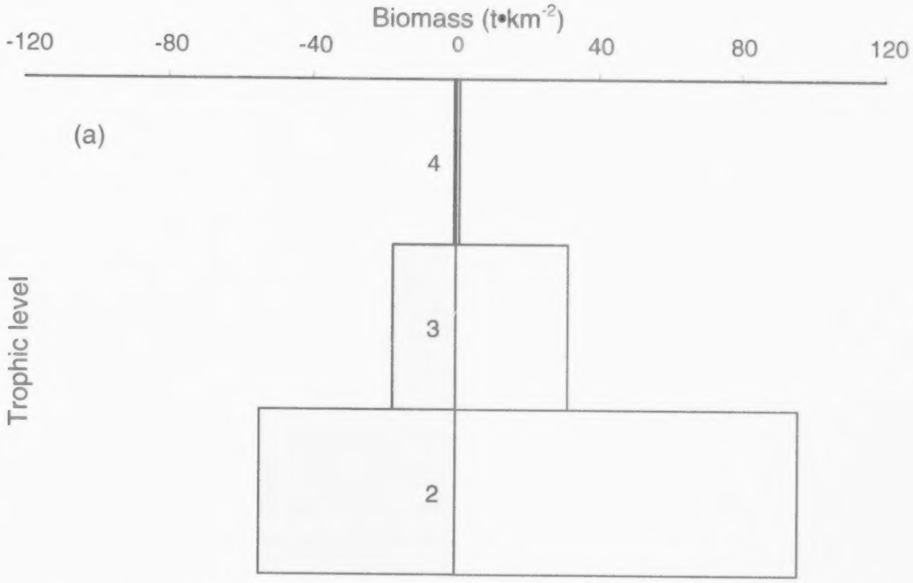


Figure 25. Distribution of biomass (t.km^2) by trophic level in the early1980s (shaded) and late 1990s (white). Early 1980s data is shown as negative for illustration only. Trophic level 2 excludes the bivalves, echinoderms, polychaetes and other benthic invertebrates since their biomass did not change from one time period to the next (from Bundy 2005).

Average trophic level of the ecosystem and piscivory increased, and the predator structure changed. During the early 1980s, cod was the main predator of fish and commercial invertebrates in the ecosystem. Other important predators included demersal piscivores (large and small) and silver hake. However, in the late 1990s, cod predation was minimal, whereas grey seals and silver hake (large and small) were the main predators of fish and commercial invertebrates. The biomass and consumption by grey seals increased and they became the main predator of fish. However, though the biomass of, and consumption by, large silver hake has decreased, it remains an important predator of capelin and small pelagics, as well as pollock, haddock, small cod and silver hake. Small demersals also appear as the main predators of sand lance and small crabs, due to the increase in the biomass of longhorn sculpin (*Myoxocephalus octodecemspinosus*). Capelin and sand lance were important predators of shrimp in the early 1990s.

An analysis of the trophic interactions of Atlantic cod in the eastern Scotian Shelf ecosystem suggests that the lack of recovery of cod after their collapse in the early 1990s can be explained by trophic factors, at least for small cod (Bundy and Fanning 2005). For large cod, predation mortality of large cod was low and few predators were identified. Grey seals have been implicated as a source of mortality of cod, especially since the collapse of cod population. In order for grey seals to account for the unknown or "other" mortality of large cod, the proportion of large cod in their diet would have to increase from the estimate of 0.1% used here, to 2%. This is not supported by the latest estimates of grey seal diet using quantitative assessment of fatty acids (S. Iverson, Dalhousie University, Halifax, N. S., Canada, unpublished data). Therefore, the most recent data do not support the hypothesis that grey seals are the cause of the high mortality on large cod.

The low biomass of small cod makes them vulnerable to both predation, and to increased competition for prey. Small cod compete for their prey with highly abundant forage fish competitors, and this likely leads to food limitation. The condition index of both large and small cod has declined since the 1970s and remains below average since the early 1990s (Figure 26). Several factors may account for this, including a decrease in water temperature, but for small cod, reduced consumption due to competition for prey is likely to be a significant contributing factor.

The most important prey of small cod was large zooplankton, in particular euphausiids and amphipods in the summer. The Ecopath models indicate a two-fold increase in large zooplankton biomass from the early 1980s (16 t km^{-2}) to the late 1990s (35 t km^{-2}). These biomass estimates are considerably higher than earlier euphausiid biomass estimates of 10 t km^{-2} in the Emerald basin and 2 t km^{-2} in the LeHave Basin (Sameoto and Cochrane 1996). However, given that the large zooplankton group includes other species in addition to euphausiids, the magnitude of the Ecopath estimates could be correct. Nevertheless, trends in euphausiid and amphipod abundance from the 1960s to the late 1990s (Sameoto 2004) do not support an increase in biomass from the early 1980s to the late 1990s.

There have been no systematic surveys of zooplankton across the Scotian Shelf. The most comprehensive data set is provided by the Continuous Plankton Recorder Survey (CPR). Data were collected on the Scotian Shelf from 1961 to 1976, then from 1991 until present. Unfortunately the missing years include the 1980s, and the trend in abundance between the early 1980s and the late 1990s is unknown. Limited CPR data for the 1980s indicates it was a period of high abundance for Calanus (stages 1-4) and euphausiids, arguably among the most important categories, in the Gulf of Maine. We observe that what happens in the Gulf of Maine is generally similar to what we see on the Scotian Shelf. Furthermore, CPR estimates of large zooplankton biomass are not considered very reliable because large zooplankton (euphausiids) are large compared to the size of the opening of the sampling net (D. Sameoto personal communication) and tend to be undersampled. With this in mind, the CPR data show that compared to the long-term mean, the abundance of euphausiids was reduced in the 1990s (Sameoto 2004). Therefore, contrary to the Ecopath model results, there was less large zooplankton biomass available in the late 1990s than the early 1980s. The implication of this is that there was insufficient large zooplankton prey to meet the consumption demands of their predators, and thus small cod would have experienced increased competition for prey, resulting in reduced per capita consumption by small cod. This hypothesis is supported by the low condition of small cod during the 1990s (Figure 26).

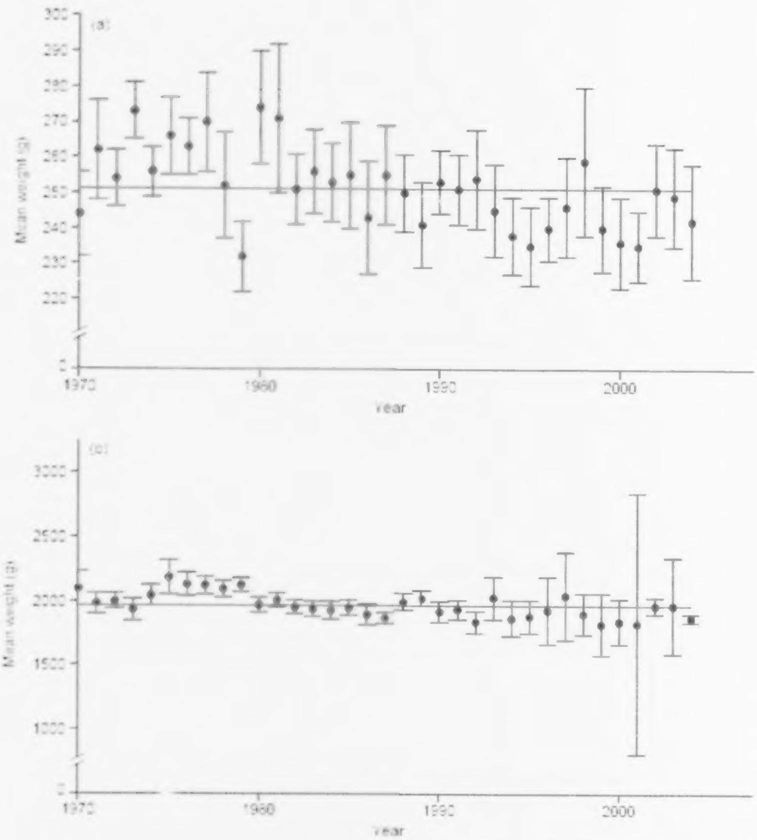


Figure 26. Condition of Atlantic cod (*Gadus morhua*), on the eastern Scotian Shelf: (a) small cod (mean weight at 30 cm) and (b) large cod (mean weight at 60 cm). Points represent the annual mean of the observations, with 95% confidence intervals of the mean. Horizontal line represents the mean over the time series (from Bundy and Fanning 2005).

Beaugrand et al. (2003) reported a similar situation for cod in the North Sea. There, since the late 1980s, the abundance, size and species diversity of copepods, the food of newly hatched larval cod, has changed, with a reduction in their preferred prey. This change in copepods was associated with a warming of sea temperature (Beaugrand et al. 2002). Copepods (small zooplankton) are also important in the diet of young larval cod on the eastern Scotian Shelf. CPR data indicate that the abundance of the dominant Calanus stage 1-4 copepods on the eastern Scotian Shelf was lower in the early 1990s than in the 1970s (Sameoto 2004, and Section 4.2 above). An analysis of Scotian Shelf Icthyoplankton Survey data and Atlantic Zone Monitoring Program data indicates that Calanus abundance decreased from the 1980s to the late 1990s (K. Frank, Bedford Institute of Oceanography, unpublished data). If copepods are important in the diet of larval cod, this could be another contributing factor to the poor condition of cod and their lack of recovery.

The cultivation/depensation theory of Walters and Kitchell (2001) proposes that top predators cultivate their young by cropping down forage species that are potential predators and competitors of their young; if top predators are removed (e.g., by fishing), this results in depensatory effects in small cod survival due to predation and competition from the now abundant forage species. We suggest that large cod kept the populations of sand lance and small pelagics (herring) in check through predation. When the numbers of large cod collapsed, this released the predation pressure on sand lance and small pelagics, leading to a large increase in their abundance. These pelagic species now compete with small cod for prey, thereby reducing their survival. Sand lance and small pelagics may also prey on small cod, either at the egg stage, pelagic stage, or once they settle on the bottom. There has been no sampling to explore this hypothesis.

This is reminiscent of a trophic cascade (Carpenter et al. 1985), but is more complex than that described for freshwater lakes. Carpenter et al. (1985) described a single stress point driving the cascade, but on the Eastern Scotian Shelf it looks more like a trophic vice. Here, with the exponential increase of seals, cod were squeezed by predation subsequent to being reduced by harvesting. Then, as the small pelagics increased, competition between small pelagics and young cod resulted in the loss of the cultivation effect. At the same time large zooplankton (a prey of forage fishes), decreased concurrently with the cod collapse and this may be a continuing result of the trophic cascade, where the release of forage fish from top-down control by cod has led to a decrease in large zooplankton prey.

The eastern Scotian Shelf has shifted to a new state where cod abundance is low. It remains low because low biomass makes them vulnerable to predation, depensation, Allee effects, where reproduction is decreased when population abundance is very low (Frank and Brickman 2000), and competition for prey. Small cod are in poor condition, predation mortality is high and there is strong competition for prey. Furthermore, the abundance of large zooplankton, the most important prey of small cod has decreased. Therefore, few small cod survive to age 4: of those that do, there is a high subsequent mortality. It is proposed that the high, unexplained mortality of large cod may be a consequence of these adversities faced by cod in their early years. Cod are in poor condition when they become large cod, and then remain that way. This is supported by the below average condition of large cod during the 1990s.

Cury et al. (2002) suggest that trophic cascades are seldom seen in open oceans and that empirical evidence indicates that bottom-up control predominates in marine ecosystems. However, other research suggests that there is evidence for top-down effects in marine ecosystems (e.g., Verity and Smetacek 1996; Bundy 2001; Worm and Myers 2003; Laurans et al. 2004) and Swain and Sinclair (2000) provided indirect evidence to support the cultivation/depensation hypothesis in the Gulf of St. Lawrence. The changes observed on the eastern Scotian Shelf suggest that top-down effects do operate, at least at higher trophic levels, but that the situation is more complex than simple top-down or bottom-up control. Frank et al. (2005) analysed the empirical data from the eastern Scotian Shelf and concluded that a trophic cascade had occurred across 4 trophic levels; the cascade began with a decrease in groundfish, causing an increase in pelagic fish, shrimp and snowcrab, a decrease in zooplankton, and increase in phytoplankton and finally, a decrease in nutrients Figure 27.

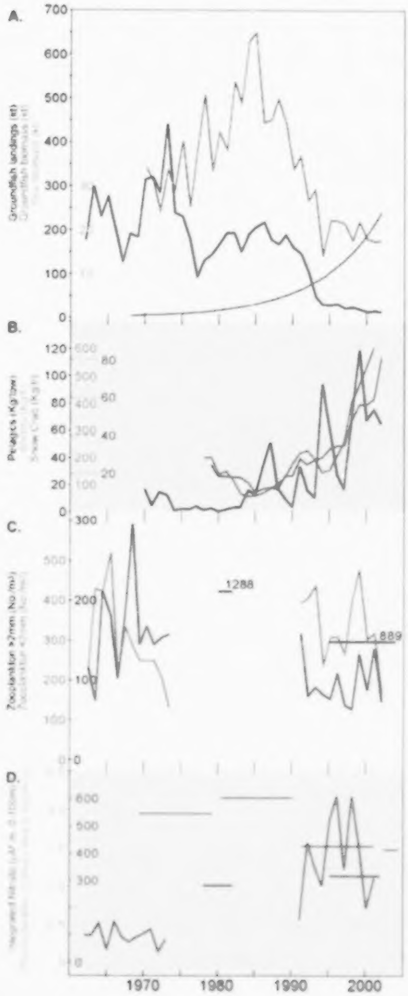


Figure 27. Illustration of a trophic cascade on the eastern Scotian Shelf across 4 trophic levels and nutrients (Figure 1 in Frank et al. 2005).

These conclusions are supported by further empirical analyses of the data from the eastern Scotian Shelf. DFO (2003) and Choi et al. (2005) explored a suite of ecosystem metrics or indicators for patterns to explain the observed changes in the ecosystem using multi-variate statistical methods. They concluded that there have been major systematic changes to the eastern Scotian Shelf ecosystem over the last 4 decades (Figure 28). Choi et al. (2005), using principle components analysis, concluded that there has been a "regime shift" on the eastern Scotian Shelf. The first principle component accounted for 33% of the variance in the data and contrasted a shift from a large bodied groundfish dominated system to a pelagic and benthic fish, and macro invertebrate dominated system. The second principle component accounted for 9 % of the variance and reflected change in ocean climate (e.g., cold intermediate layer, bottom T°C and Gulf Stream frontal position). Since the change in environmental conditions preceded the changes in the biotic conditions, this indicates a potential causal effect.

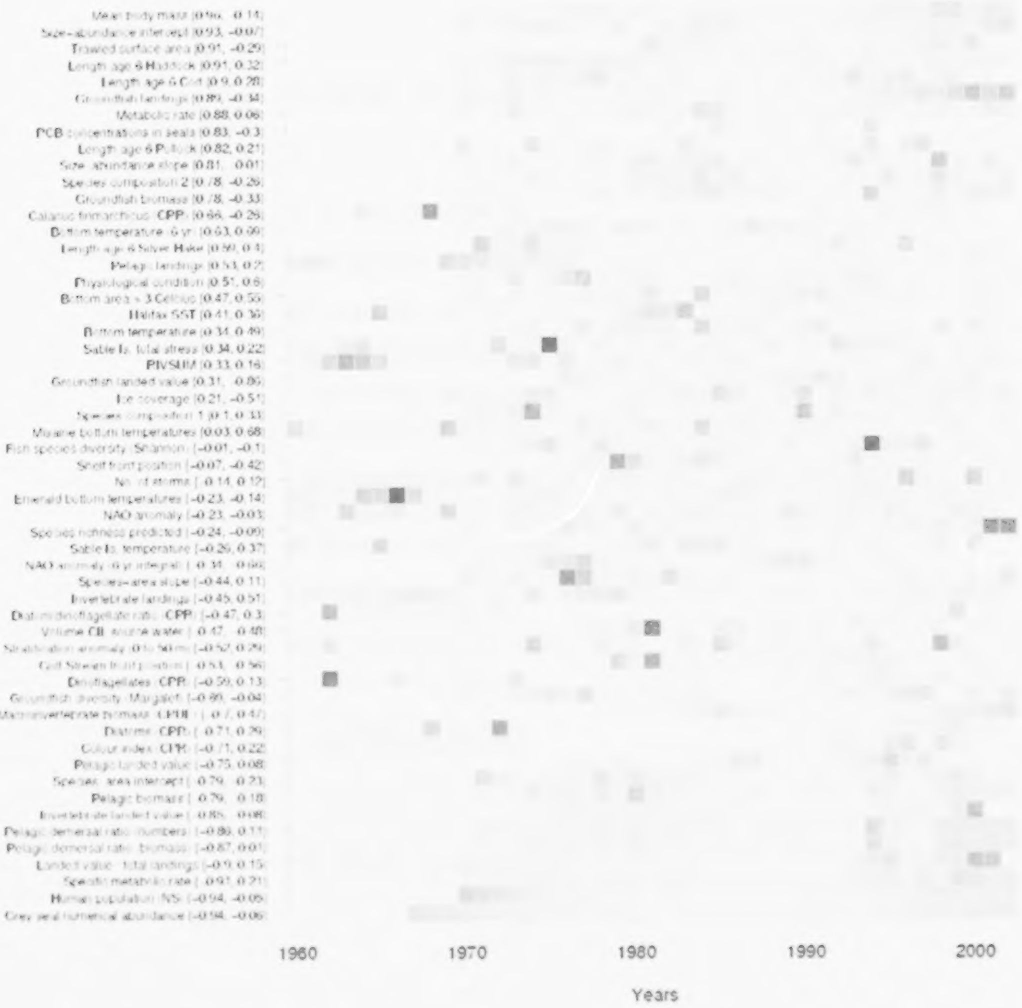


Figure 28. Sorted table of the standardised anomalies (standard deviation units) of the ecosystem indicators of the eastern Scotian Shelf (taken from Choi et al. 2005; Figure 3).

Despite a fisheries moratorium, there has been no recovery of the cod population on the eastern Scotian Shelf, and the structure of the ecosystem remains dominated by the high abundance of pelagic fish, shrimp, snow crab and grey seals. It is likely that the eastern Scotian Shelf ecosystem is in a new, relatively stable state, unable to return to its former state due to hysteresis in the system (Figure 29). In addition to the top-down control and the cultivation/depensation effects described above that block the return path in Figure 29, Choi et al. (2005) suggest that bottom-up forces may also be acting to keep the eastern Scotian Shelf in its current steady state. There has been a higher degree of stratification of the eastern Scotian Shelf since around 1990, leading to a de-coupling of the benthic-pelagic systems. This reduces the amount of organic matter descending from the overlying water column, resulting in reduced primary and secondary production, and a reduced food supply for the benthic communities.

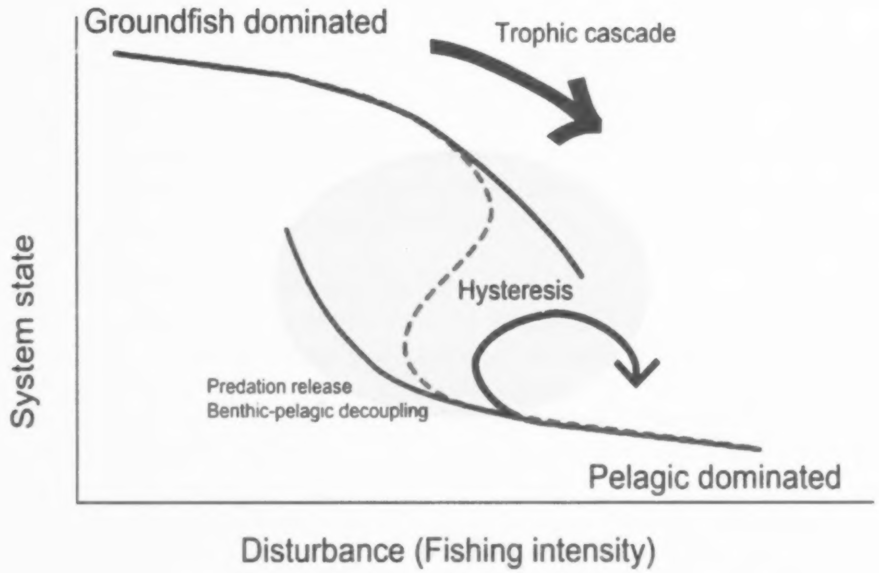


Figure 29. Conceptual model of an ecosystem showing hysteresis. The forward and backward trajectories are decoupled such that it is not possible to return to the former groundfish dominated state by reducing fishing pressure. Adapted from Choi et al. 2005, Figure 6.

7.0 REFERENCES

Alverson, L., Freeberg, M.H., Murawski, S.A., and Pope, J.G. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. Rome, FAO.: 233 p.

Ambrose, R.F., and Anderson, T.W. 1990. Influence of an artificial reef on the surrounding infaunal community. Mar. Biol. 107: 41-52.

Armsworthy, S.L., Crandford, P.J., and Lee, K. [Eds.] 2005. Offshore oil and gas environmental effects monitoring: Approaches and technologies. Proceedings of a Conference held May 26-30, 2003, Bedford Institute of Oceanography, Dartmouth, NS.

Austin, D., Bowen, W.D., and McMillan, J.I. 2004. Intraspecific variation in movement patterns: modeling individual behaviour in a large marine predator. Oikos 105: 15-30.

Beck, C.A., Bowen, W.D., and Iverson, S.J. 2003. Seasonal energy storage and expenditure in a phocid seal: evidence of sex-specific trade-offs. Journal of Animal Ecology 72: 280-291.

Beck, C.A., Bowen, W.D., Iverson, S.J., and Blanchard, W. (Under review.) Dietary niche breadth in a large marine predator: Sex-season interactions in grey seals based on quantitative fatty acid signature analysis. Ecology.

Beaugrand, G., Brander, K.M., Lindley, J.A., Souissi, S., and Reid, P.C. 2002. Plankton effect on cod recruitment in the North Sea. Nature: 426 (6967): 661-664.

Beaugrand, G., Reid, P.C., Ibanez, F., Lindley, J.A., and Edwards, M. 2003. Reorganization of North Atlantic marine copepod biodiversity and climate. Science 296(5573): 1692-1694.

Bianchi, G., Gislason, H., Graham, K., Hill, L., Koranteng, K., Manichkand-Heileman, S., Paya, I., Sainsbury, K., Sanchez, F., Jin, X., and Zwanenburg, K.C.T. 2000. Impacts of fishing on the size composition and diversity of demersal fish communities. ICES Journal of Marine Science 57: 558-571.

Boesch, D.F., and Rabelais, N.N. [Eds] 1987. Long-term environmental effects of offshore oil and gas development. Elsevier Applied Sci. London & NY.

Bohnsack, J.A., and Sutherland, D.L. 1985. Artificial reef research: A review with recommendations for future priorities. Bulletin of Marine Science 37(1): 11-39.

Booman, C., and Føyn, L. 1996. Effects of the water soluble fraction of crude oil on marine fish larvae and crustaceans, Chapter 15, 149-162 pp; *In* M. Reed and S. Johnsen [Eds.] Produced Water 2: Environmental Issues and Mitigation Technologies. Plenum Press, New York.

Boudreau, P.R., Gordon, D.C., Harding, G.C., Loder, J.W., Black, J., Bowen, W.D., Campana, S., Cranford, P.J., Drinkwater, K.F., Van Eeckhaute, L., Gavaris, S., Hannah, C.G., Harrison, G., Hunt, J.J., McMillan, J., Melvin, G.D., Milligan, T.G., Muschenheim, D.K., Neilson, J.D., Page, F.H., Pezzack, D.S., Robert, G., Sameoto, D., and Stone, H. 1999. The possible environmental impacts of petroleum exploration activities on the Georges Bank ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 2259.

Boulva, J., and McLaren, I.A. 1979. Biology of the harbour seal, *Phoca vitulina*, in eastern Canada. Bull. Fish. Res. Brd., Can. 200: 1-24.

Bowen, W.D. 1997. Role of marine mammals in aquatic ecosystems. Marine Ecology Progress Series 158: 267-274.

Bowen, W.D., and Siniff, D.B. 1999. Distribution, population biology, and feeding ecology of marine mammals, 423-484 pp.; *In* J.E. Reynolds, III and S.A. Rommel [Eds.]. Biology of Marine Mammals. Smithsonian Press, Washington, D.C.

Bowen, W.D., and Harrison, G.D. 1996. Comparison of harbour seal diets in two habitats in Atlantic Canada. Canadian Journal of Zoology 74: 125-135.

Bowen, W.D., and Harrison, G.D. [Eds.]. 2006. Seasonal and interannual variability in grey seal diets on Sable Island, Eastern Scotian Shelf. NAMMCO Scientific Publication.

Bowen, W.D., McMillan, J.I., and Mohn, R. 2003. Sustained exponential population growth of the grey seal on Sable Island. ICES J. Marine Sci. 60: 1265-1374.

Bowen, W.D., Lawson, J.W., and Beck, B. 1993. Seasonal and geographic variation in the species composition and size of prey consumed by grey seals (*Halichoerus grypus*) on the Scotian shelf. Can. J. Fish. Aquat. Sci. 50: 1768-1778.

Bowen, W.D., Beck, C.A., Iverson, S.J., Austin, D., and McMillan, J.I. 2005. Linking predator foraging behaviour and diet with variability in continental shelf ecosystems: grey seals of eastern Canada. *In* I.L. Boyd and S. Wanless [Eds] Management of Marine Ecosystems: Monitoring Changes in Upper Trophic Levels. The Zoological Society of London, London, UK.

Brander, K.M. 1995. The effects of temperature on growth of Atlantic cod (*Gadus morhua* L.) ICES J. Mar. Sci. 52: 1-10 pp.

Breeze, H., Fenton, D.G., Rutherford, R.J., and Silva, M.A. 2002. The Scotian Shelf: An ecological overview for ocean planning. Can. Tech. Rep. Fish. Aquat. Sci. 2392: x + 259 p.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E., and Davis, T. 1975. Atlas of eastern Canadian seabirds. Canadian Wildlife Service, Ottawa.

Bundy, A. 2001. Fishing on ecosystems: the interplay of fishing and predation in Newfoundland-Labrador. Can. J. Fish. Aquat. Sci 58: 1153-1167.

Bundy, A. 2004. Mass balance models of the eastern Scotian Shelf before and after the cod collapse and other ecosystem changes. Can. Tech. Rep. Fish. Aquat. Sci. 2520: xi +140 p +App.

Bundy, A. 2005. Structure and functioning of the eastern Scotian Shelf ecosystem before and after the collapse of groundfish stocks in the early 1990s. Can. J. Fish. Aquat. Sci 62: 1453-1473.

Bundy, A., and Fanning, L.P. 2005. Can Atlantic cod (*Gadus morhua*) recover? Exploring trophic explanations for the non-recovery of the cod stock on the eastern Scotian Shelf, Canada. Can. J. Fish. Aquat. Sci 62: 1474-1489.

Canada-Newfoundland Offshore Petroleum Board. 2003. Strategic environmental assessment, Laurentian Sub-basin. Prepared by Jacques Whitford Environment Limited, St. John's, N.F.

Canada-Nova Scotia Offshore Petroleum Board. 2003. Strategic environmental assessment of potential exploration rights issuance for eastern Sable Island Bank, Western Banquereau Bank, The Gully Trough and the Eastern Scotian Slope. Prepared by Jacques Whitford Environment Limited, Dartmouth, N.S.

Canada-Nova Scotia Offshore Petroleum Board 2005. CNSOPB Annual Report, 2004-2005.

Canada-Nova Scotia Offshore Petroleum Board. 2005. Strategic environmental assessment of the Misaine Bank area. Prepared by CEF Consultants Limited, Halifax, N.S.

Campana, S.E., and Joyce, W.N. 2004. Temperature and depth associations of porbeagle shark (*Lamna nasus*) in the Northwest Atlantic. Fish. Oceanogr. 13: 52-64.

Campana, S., Joyce, W., and Marks, L. 2003. Status of the porbeagle shark (*Lamna nasus*) population in the northwest Atlantic in the context of species at risk. CSAS Res. Doc. 2003/007.

Campana, S., Marks, L., Joyce, W., and Kohlen, N. 2004a. Influence of recreational and commercial fishing on the blue shark (*Prionace glauca*) population in Atlantic Canadian waters. CSAS Res. Doc. 2004/069: 67 p.

Campana, S., Marks, L., and Joyce, W. 2004b. Biology, fishery and stock status of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Canadian Waters. CSAS Res. Doc. 2004/094: 33 p.

Campana, S., Gonzalez, P., Joyce, W., and Marks, L. 2002. Catch, bycatch and landings of blue shark (*Prionace glauca*) in the Canadian Atlantic. CSAS Res. Doc. 2002/101: 40 p.

Campana, S.E., Jones, C., McFarlane, G.A., and Myklevoll, S. 2006. Bomb dating and age validation using the spines of spiny dogfish (*Squalus acanthias*). Envir. Biol. Fish. (In press).

Campana, S., Marks, L., Joyce, W., and Harley, S. 2001. Analytical assessment of the porbeagle shark (*Lamna nasus*) population in the Northwest Atlantic, with estimates of long-term sustainable yield. CSAS Res. Doc. 2001/067.

Campana, S.E., Mohn, R.K., Smith, S.J., and Chouinard, G. 1995. Spatial visualization of a temperature-based growth model for Atlantic cod (*Gadus morhua*) off the eastern coast of Canada. Can. J. Fish. Aquat. Sci. 52: 2445-2456.

Campana, S., Marks, L., Joyce, W., Hurley, P., Showell, M., and Kulka, D. 1999. An analytical assessment of the porbeagle shark (*Lamna nasus*) population in the northwest Atlantic. CSAS Res. Doc. 99/158.

Campana, S., Joyce, W., Marks, L., Natanson, L.J., Kohler, N.E., Jensen, C.F., Mello, J.J., Pratt, Jr., H.L., and Myklevoll, S. 2002a. Population dynamics of the porbeagle in the northwest Atlantic Ocean. North Am. J. Fish. Management 22: 106-121.

Carpenter, S.C., Kitchell, J.F., and Hodgson, J.R. 1985. Cascading trophic interactions and lake productivity. Bioscience 35: 634-639.

Carter, J.A., MacKnight, S.D., and Ross, C.W. 1985. The impact of drilling-waste disposal on trace metals in scallop tissue and sediments near Sable Island, 27-52 pp. *In* Proceedings of the Tenth Annual Aquatic Toxicity Workshop, November 7-10, 1983, Halifax, Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1368: 27-52.

CCME. 1999 (updated 2001). Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment.

CETAP. 1982. A characterization of marine mammals and turtles in the mid- and North Atlantic areas of the US outer Continental Shelf. Cetacean and Turtle Assessment Program, Univ. Rhode Island. US Bureau of Land Management, Contract No. AA551-CTB-48., Washington, DC.

Christian, J.R., Mathieu, A., Thompson, D.H., White, D., and Buchanan, R. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Environmental Research Funds Project No. 144. Calgary.

Chapman, P.M., Anderson, B., Carr, S., Engle, V., Green, R., Hameedi, J., Harmon, M., Harverland, P., Hyland, J., Ingersoll, C., Long, E., Rodgers Jr., J., Salazer, M., Sibley, P.K., Smith, P.J., Swartz, R.C., Thompson, B., and Windom, H. 1997. General guidelines for using the Sediment Quality Triad. Mar. Pollut. Bull. 34:368-372.

Choi, J.S., Frank, K.T., Petrie, B.D., and Leggett, W.C. 2005. Integrated assessment of a large marine ecosystem: A case study of the devolution of the eastern Scotian Shelf, Canada. Oceanography and Marine Biology: An Annual Review, 2005, 43: 47-67.

Chuenpagdee, R., Morgan, L.E., Maxwell, S.M., Norse, E.A., and Pauly, D. 2003. Shifting gears: assessing collateral impacts of fishing methods in the U.S. waters. Frontiers in Ecology and the Environment 10(1): 517-524.

Clarke, K.R., and Warwick, R.M. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth

Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology, 69: 785-798.

Cord, A.H. 1997. Appraisal of the experience of marine fouling in the North Sea. Report to Mobil Oil Canada Properties.

Cranford, P.J. in press. Chapter 12, In S. Shumway and J. Parsons [Eds.], Scallops: Biology, Ecology and Aquaculture. 2nd Edition.

Cranford, P.J., 1995. Relationships between food quantity and quality and absorption efficiency in sea scallops *Placopecten magellanicus* (Gmelin). J. Exp. Mar. Biol. Ecol. 189: 123–142.

Cranford, P.J., and Hargrave, B.T. 1994. *In situ* time-series measurements of ingestion and absorption rates of suspension-feeding bivalves: *Placopecten magellanicus* (Gmelin). Limnology and Oceanography 39: 730–738.

Cranford, P.J., and Hill, P.S. 1999. Seasonal variation in food utilization by the suspension-feeding bivalve molluscs *Mytilus edulis* and *Placopecten magellanicus*. Mar. Ecol. Prog. Ser. 190: 223–239

Cranford, P.J., and Gordon, D.C. 1991. Chronic sublethal impact of mineral oil-based drilling mudcuttings on adult sea scallops. Mar. Poll. Bull. 22: 339–344.

Cranford, P.J., and Gordon Jr., D.C. 1992. The influence of dilute clay suspensions on the sea scallop (*Placopecten magellanicus*) feeding activity and tissue growth. Neth. J. Sea Res. 30: 107–120.

Cranford, P.J., Emerson, C.W., Hargrave, B.T., and Milligan, T.G. 1998. *In situ* feeding and absorption responses of sea scallops *Placopecten magellanicus* (Gmelin) to storm-induced changes in the quantity and composition of the seston. J. Exp. Mar. Biol. Ecol. 219: 45–70.

Cranford, P.J., Gordon Jr., D.C., Lee, K., Armsworthy, S.L., and Tremblay, G.-H. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Mar. Env. Res.: 48: 225-256.

Cranford, P.J., Gordon Jr., D.C., Hannah, C.G., Loder, J.W., Milligan, T.J., Muschenheim, D.K., and Shen, Y. 2003. Modelling potential effects of petroleum exploration drilling on northeastern Georges Bank scallop stocks. Ecol. Modelling 166: 19–39.

Cury, P., Shannon, L., and Shin, Y.J. 2002. The functioning of marine ecosystems: A fisheries perspective. *In* M.G.V. Sinclair [Ed.] Responsible Fishing in the Marine Ecosystem. CAB International , Wallingford.

Cury, P., Bakun, A., Crawford, R.J.M., Jarre, A., Quiñones, R., Shannon, L.J., and Verheye, H.M. 2000. Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. ICES J. Mar. Sci. 57: 603-618.

Davis, R.A., Thomson, D.H., and Malme, C.I. 1998. Environmental assessment of seismic exploration on the Scotian Shelf. Prepared for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., Imperial Oil Ltd., and for submission to CNSOPB.

Davies, J.M., Bedborough, D.R., Blackman, R.A.A., Addy, J.M., Applebee, J.F., Grogan, W.C., Parker, J.G., and Whitehead, A. 1989. The environmental effects of oil-based drilling in the North Sea. Chapter 3 *In* F.R. Engelhardt, J.P. Ray, and A.H. Gillam [Eds.] Drilling Wastes. Elsevier Applied Science, London.

Dayton, P.K., Thrush, S.F., Agardy, M.T., and Hofman, R.J. 1995. Environmental effects of fishing. Aquat. Cons. Mar. Freshw. Ecosys. 5: 205-232.

DFO. 1998. Northern shrimp on the eastern Scotian shelf. DFO Sci. Stock Status Rep. C3-15 (1998).

DFO. 2001. Proceedings of the national workshop on objectives and indicators for ecosystem-based management, Sidney, British Columbia, 27 February – 2 March 2001. Can. Sci. Advis. Secr. Proc. 2001/09.

DFO. 2003. State of the eastern Scotian Shelf ecosystem. Can. Sci Adv. Sec. Ecosystem Status Rep. 2003/004.

DFO. 2004a. Review of scientific information on impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/002.

DFO. 2004b. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/003.

Din, Z.B., and Abu, A.B. 1992. Sub lethal effects of produced water from crude oil terminals on the clam *Donax faba,* 445-454 pp; *In* J.P. Ray and F.R. Engelhart [Eds.], Produced Water. Plenum Press, New York.

Dodge, R.E. 1982. Effects of drilling mud on the reef-building coral *Montastrea annularis.* Mar. Biol. 71: 141-147.

Dodge, R.E., and Szmant-Froelich, A. 1985. Effects of drilling fluids on reef-building corals: A review, 341-364 pp.; *In* I.W. Duedall, D.R. Kester, and P.K. Park [Eds.] Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean. John Wiley & Sons, Inc.

Ellertsen, B., Fossum, P., Solemdal, P., and Sundby, S. 1989. Relation between temperature and survival of eggs and first-feeding larvae of northeast Arctic cod (*Gadus morhua* L.). Rapp. P.-v. Réun. Cons. int. Explor. Mer., 191, 209-219.

Ellis, M.S., Wilson-Ormond, E.A., and E.N. Powell. 1996. Effects of gas-producing platforms on continental shelf macroepifauna in the northwestern Gulf of Mexico: Abundance and size structure. Can. J. Fish. Aquat. Sci. 53: 2589-2605.

Engelhardt, F.R., Ray, J.P., and Gillam, A.H. [Eds.]. 1989. Drilling Wastes. *In* Proceedings of an International Conference on Drilling Wastes, held at Calgary, Alberta, in 1988]. Elsevier Science Publishers Ltd, Barking, England.

Ernst, R.J., Ratnayake, W.M.N., Farquharson, T.E., Ackman, R.G., Tidmarsh, W.G., and Carter, J.A. 1989. Tainting of Atlantic cod (*Gadus morhua*) by petroleum hydrocarbons, 827-839 pp.; *In* F.R. Engelhardt, J.P. Ray, and A.H. Gillam [Eds.] Drilling Wastes. Elsevier Applied Science, London.

Fader, G.B., and Strang, J. 2002. An interpretation of multibeam bathymetry from The Gully, outer Scotian Shelf: Materials, habitats, slopes, features and processes. In advances in understanding The Gully ecosystem: A summary of research projects conducted at the Bedford Institute of Oceanography (1999-2001). [Eds.] D.C. Gordon and D.G. Fenton. Can. Tech. Rep. Fish. Aquat. Sci. 2377: 5-16.

Fader, G.B., King, L.H., and Josenhans, H.W. 1982. Surficial geology of the Laurentian Channel and the western Grand Banks of Newfoundland. Geological Survey of Canada Paper 81-22.

Fader, G.B.J., Rickrill, R.A., Todd, B.J., Courtney, R.C., and Parrott, D.R. 1998. Science Review 1996 and 1997, Bedford Institute of Oceanography. Dartmouth, NS: Fisheries and Oceans Canada and Natural Resources Canada.

Fitzwater, S.E., Knauer, G.A., and Martin, J.M. 1982. Metal contamination and its effect on primary production measurements. Limnol. Oceanogr. 27: 544-551.

Frank, K.T., and Brickman, D. 2000. Allee effects and compensatory population dynamics within a stock complex. Can. J. Fish. Aquat. Sci. 57: 513-517.

Frank, K.T., Simon, J., and Carscadden, J.E. 1996. Recent excursions of capelin (*Mallotus villosus*) to Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Can. J. Fish. Aquat. Sci. 53: 1473-1486.

Frank, K.T., Petrie, B., Choi, J.S., and Leggett, W.C. 2005. Trophic cascades in a formerly cod-dominated ecosystem. Science 308: 1621-1623.

Fuller, S., and Cameron, P. 1998. Marine benthic seascapes: Fishermen's perspectives. Marine Issues Committee Special Publication Number 3. Halifax, NS: Ecology Action Centre.

Furness, R.W., and Monaghan, P. 1987. Seabird ecology. London: Blackie.

Gaston, A.J., and Jones, I. 1998. The Auks. Oxford University Press. Oxford.

GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Pollution). 1993. Impact of oil and related chemicals on the marine environment. Rep. Stud. GESAMP (50): 180 pp.

Gordon, D.C. [Ed.] 1988. An assessment of the possible environmental impacts of exploratory drilling on Georges Bank fishery resources. Can. Tech. Rep. Fish. Aquat. Sci. No.1633.

Gordon, D.C., Jr., Griffiths, L.D., Hurley, G.V., Muecke, A.L., Muschenheim, D.K., and Wells, P.G. [Eds.]. 2000. Understanding the environmental effects of offshore hydrocarbon development. Can. Tech. Rep. Fish. Aquat. Sci. 2311.

Gordon, D.C. Jr., Gilkinson, K.D., Kenchintgon, E.L.R., Prena, J., Bourbonnais, C., MacIsaac, K., McKeown, D.L., and Vass, W.P. 2002. Summary of the Grand Banks otter trawling experiment (1993-1995): Effects on benthic habitat and communities. Can. Tech. Rep. Fish. Aquat. Sci. 2416: 72 pp.

Gowans, S., Whitehead, H., Arch, J.K., and Hooker, S.K. 2000. Population size and residency patterns of northern bottlenose whales (*Hyperoodon ammpullatus*) using the Gully, Nova Scotia. J. Cetacean Res. Manage. 2: 201-210.

Harley, S.J., and Myers, R.A. 2000. Hierarchical Bayesian models of length-specific catchability of research trawl surveys. Can. J. Fish. Aquat. Sci. 58: 1569–1584

Haedrich, R.L., and Barnes, S.M. 1997. Changes over time of the size structure in an exploited shelf fish community. Fish. Res. 31: 229-239.

Halliday, R., and Koeller, P. 1980. A history of Canadian groundfish trawling surveys and data usage in ICNAF Divisions 4TVWX, 27-41 pp.; *In* Doubleday W.G. and D. Rivard [Eds.] Bottom Trawl Surveys. Can. Spec. Pub. Fish. Aquat. Sci. 58.

Hannah, C.G. and A. Drozdowski. 2005. Characterization of drift and dispersion of drilling mud on three Canadian offshore banks. Marine Pollution Bulletin. 50, 1433-1443.

Hannah, C.G., Loder, J.W., Shen, Y., and Muschenheim, D.K. 1995. bblt: Formulation and exploratory applications of a benthic boundary layer transport model. Can. Tech. Rep. Hydrog. Ocean Sci. 166.

Hammill, M.O., Stenson, G.B., Myers, R.A., and Stobo, W.T. 1998. Pup production and population trends of the grey seal (*Halichoerus grypus*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 55: 423-430.

Harrison, W.G. and D.G. Fenton. 1998. The Gully: A scientific review of its environment and ecosystem. CSAS Res. Doc. 1998/83

Head, E.J.H., and Harris, L.R. 1994. Feeding selectivity by copepods grazing on natural mixtures of phytoplankton determined by HPLC analysis of pigments. Mar. Ecol. Prog. Ser. 110: 75-83.

Head, E.J.H., and Harris, L.R. 2004. Estimating zooplankton biomass from dry weights of groups of individual organisms. CSAS Res. Doc. 2004 /045.

Head, E.J.H., Brickman, D., and Harris, R.L. 2005. An exceptional haddock year class and unusual environmental conditions on the Scotian Shelf in 1999. J. Plankton Res. (Under review)

Head, E.J.H., Harris, L.R., and Petrie, B. 1999. Distribution of *Calanus* spp. on and around the Nova Scotia shelf in April: Evidence for an offshore source of *Calanus finmarchicus* to the central and western regions. Can. J. Fish. Aquat. Sci. 56: 2463-2476.

Hooker, S.K., and Baird, R.W. 2001. Diving and ranging behaviour of odontocetes: a methodological review and critique. Mammal Rev. 31: 81-105.

Hudson, J.H., Shinn, E.A., and Robbin, D.M. 1982. Effects of offshore oil drilling on Philippine reef corals. Bull. Mar. Sci. 32: 890-908.

Huettmann, F. 2003. Estimates of abundance, biomass and prey consumption for selected seabird species for the eastern and western Scotian Shelf, 1966-1992. DFO Report: 34 p.

Huettmann, F., and Diamond, A.W. 2001. Seabird colony locations and environmental determination of seabird distribution: A spatially explicit seabird breeding model in the Northwest Atlantic. Ecological Modelling 141: 261-298.

Hunter, M.D., and Prince, P.W. 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. Ecology 73: 724-732.

Hutcheson, M.S., Stewart, P.L., Odense, R., and Fowler, B. 1987. The effects of mineral oiled drill cuttings on marine invertebrates: Lethality, hydrocarbon accumulation/depuration, burrowing success and moulting, 9-46 pp.; *In* Pollution Physiology of Estuarine Organisms. Belle Baruch Library in Marine Science. Vol. 17. University of North Carolina Press.

Huston, M.A. 1979. A general hypothesis of species diversity. Am. Nat. 113:81-101.

IOC. 1996. A strategic plan for the assessment and prediction of the health of the ocean: A module of the Global Ocean Observing System. Prepared by the Health of the Ocean Panel of the Joint Scientific and Technical Committee for the Global Ocean Observing System, International Oceanographic Commission. IOC/INF-1044.

Innis. 1954. The cod fishery: The history of an international economy. University of Toronto Press. 522 p.

Iverson, S.J., Field, C., Bowen, W.D., and Blanchard, W. 2004. Quantitative fatty acid signature analysis: A new method of estimating predator diets. Ecological Monographs 74: 211-235.

Jackson, J.B.C, Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science Vol. 293: 629-638.

Jensen, C.F., Natanson, L.J., Pratt, H.L., Kohler, N.E., and Campana, S.E. 2002. The reproductive biology of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. Fish. Bull. 100: 727-738.

Johnson, K.A. 2002. A review of national and international literature on the effects of fishing on benthic habitats. NOAA Technical Memorandum NMFS-F/SPO-57: 72 p.

Joyce, W.N., Campana, S.E., Natanson, L.J., Kohler, N.E., Pratt Jr., H.L., and Jensen, C.F. 2002. Analysis of stomach contents of the porbeagle shark (*Lamna nasus*) in the northwest Atlantic. ICES J. Mar. Sci. 59:1263-1269.

Kaiser, M.J., Spence, F.E., and Hart, P.J.B. 2000. Fishing gear restrictions and conservation of benthic habitat complexity. Conservation Biology 14: 1512-1525.

Kaiser, M.J., 2003. Detecting the effects of fishing on seabed community diversity: Importance of scale and sample size. Conservation Biology 17: 512–520.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., and Poiner, I.R. 2002. Modification of marine habitats by trawling activities: Prognosis and solutions. Fish and Fisheries 3: 114–136

Kenney, R.D., Scott, G.P., Thompson, T.J., and Winn, H.E. 1997. Estimates of prey consumption and trophic impacts of cetaceans in the USA northeast continental shelf ecosystem. J. Northw. Atl. Fish. Sci. 22: 155-171.

Kiddon, J.A. et al. 2003. Ecological condition of US mid-Atlantic estuaries, 1997-1998. Mar. Poll. Bull. 46: 1224-1244.

King, L.H. 1970. Surficial geology of the Halifax-Sable Island map area. Marine Sciences Branch, Department of Energy Mines and Resources, Ottawa. Paper 1.

King, L.H. 1980. Aspects of regional surficial geology related to site investigation requirements – eastern Canadian Shelf, 37-59 pp.; *In* D.A. Ardus [Ed.] Offshore Site Investigation. Proceedings of a Conference held in March 1979. London: Graham & Trotman.

King, L.H., and Fader, G.B.J. 1986. Wisconsonian glaciation of the Atlantic continental shelf of southeast Canada. Geological Survey of Canada Bulletin #363.

King, L.H., and MacLean, B. 1976. Geology of the Scotian Shelf. Geological Survey of Canada Paper 74-31. (Marine Sciences Paper 7).

Kostylev, V.E. 2004. Habitat management template for Scotian Shelf habitat mapping. CSAS Res, Doc. (Manuscript)

Krause, P.R., Osenberg, C.W., and Schmitt, R.J. 1992. Effects of produced water on early life stages of a sea urchin: Stage-specific responses and delayed expression, 431-444 pp.; *In* J.P. Ray and F.R. Engelhart [Eds.] Produced Water. Plenum Press, New York.

Laurans, M., Gascuel, D., Chassot, E., and Thiam, D. 2004. Changes in the trophic structure of fish demersal communities in West Africa in the three last decades. Aquat. Living Resour. 17 (2004): 163-173.

Laurinolli, M.H., Harris, L.E., Bundy, A., and Fanning, L.P. 2004. Compilation of fish stomachs data from the Scotian Shelf and Bay of Fundy (1958-2002): CDEENA diet composition and consumption estimation project. Can. Tech. Rep. Fish. Aquat. Sci. 2518: vi + 90 pp.

Lee, K., Azetsu-Scott, K., Cobanli, S.E., Dalziel, J., Niven, S., Wohlgeschaffen, G., and Yeats, P. 2005. Overview of potential impacts from produced water discharges in Atlantic Canada, 319-342 pp.; *In* S.L. Armsworthy, P.J. Cranford, and K. Lee [Eds.] Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Methodologies. Battelle Press. Columbus, Ohio.

Levin, S.A. 1999. Fragile dominion: Complexity and the commons. Perseus Publishing, Cambridge, MA.

Lock, A.R., Brown, R.G.B., and Gerriets, S.H. 1994. Gazetteer of marine birds in Atlantic Canada. Canadian Wildlife Service, Ottawa, Ont.

Longhurst, A. 1999. Does the benthic paradox tell us something about surplus production models. Fisheries Research, 867: 1-7.

Lucas, Z., and Stobo, W.T. 2000. Shark-inflicted mortality on a population of harbour seals (*Phoca vitulina*) at Sable Island, Nova Scotia. Journal of Zoology, London 252: 405-414.

MacLean, B., and King, L.H. 1971. Surficial geology of the Banquereau and Misaine Bank map area. Geological Survey of Canada Paper 71-52.

MacLean, B., Fader, G.B., and King, L.H. 1977. Surficial geology of Canso Bank and adjacent areas. Geological Survey of Canada Paper 76-15.

Mahon, R., and Neilsen, J.D. 1987. Diet changes in Scotian Shelf haddock during the pelagic and demersal phases of the first year of life. Mar. Ecol. Prog. Ser. 37: 123-130.

Mansfield, A.W., and Beck, B. 1977. The grey seal in eastern Canada. Fish. Mar. Ser. Tech. Rep. 704: 1-81.

Martec Limited, CEF Consultants Ltd, DRDC Atlantic, St. Francis Xavier University. 2004. Effects of pipelines/gathering lines on snow crab and lobster.

McCord, M.E., and Campana, S.E. 2003. A quantitative assessment of the diet of the blue shark (*Prionace glauca*) off Nova Scotia, Canada. J. Northw. Atl. Fish. Sci. 32: 57-63.

McLaren, I.A. 1993. Growth in pinnipeds. Biol. Rev. 68: 1-79.

Milligan, T.G., Tedford, T., Muschenheim, D.K., and Hannah, C.G. 2005. Quantifying fine-grained drill waste in Scotian Shelf suspended sediments, 201-226 pp.; *In* P. Cranford, S. Armsworthy, and K. Lee [Eds.] Environmental Effects Monitoring: Approaches and Technologies.

Moffett, J.W., and Brand, L.E. 1996. Production of strong, extracellular Cu chelators by marine cyanobacteria in response to Cu stress. Limnol. Oceanogr. 41: 388-195.

Mohn, R., and Bowen, W.D. 1996. Grey seal predation on the eastern Scotian Shelf: modelling the impact on Atlantic cod. Can. J. Fish. Aquat. Sci. 53: 2722-2738.

Montagna, P.A., and Harper Jr., D.E. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53: 2567-2588.

Morgan, L.E., and Chuenpagdee, R. 2003. Shifting gears: addressing the collateral impacts of fishing methods in US waters. Pew Science Ser, Washington, DC.

Mullino, M.M., Rayle, M.F., Francis, J.C., and Poirrier, M.A. 1996. Delineation of benthic impact and recovery attwo produced water discharge sites in inshore Louisiana, 177-194 pp.; *In* M. Reed and S. Johnsen [Eds.] Produced Water 2 Environmental Issues and Mitigation Technologies. Plenum Press, New York.

Muschenheim, D.K., and Milligan, T.G. 1996. Flocculation and accumulation of fine drilling waste particulates on the Scotian Shelf (Canada). Mar. Pollut. Bull. 32: 740-745.

Muschenheim, D.K., Milligan, T.G., and Gordon Jr., D.C. 1995. New technology and suggested methodologies for monitoring particulate wastes discharged from offshore oil and gas drilling platforms and their effects on the benthic boundary layer environment. Can. Tech. Rep. Fish. Aquat. Sci. 2049.

Natanson, L.J., Mello, J.J., and Campana, S.E. 2002. Validated age and growth of the porbeagle shark, *Lamna nasus*, in the western North Atlantic Ocean. Fish. Bull., U.S. 100: 266-278.

National Research Council. 1985. Oil in the sea. Inputs, fates and effects. National Academy Press, Washington, D.C.

National Research Council (NRC). 1996. The Bering Sea ecosystem. National Academy Press, Washington, D.C.

National Research Council (NRC). 2002. A century of ecosystem science: Planning long-term research in the Gulf of Alaska. National Academy Press, Washington, D.C.

Neff, J.M. 1987. Biological effects of drilling fluids, drill cuttings and produced water. Chapter 10, *In*. D.F. Boesch and N.N. Rabelais [Eds.] Long-Term Environmental Effects of Offshore Oil and Gas Development. Elsevier Applied Sci. London.

Neff, J.M., and Sauer Jr., T.C. 1996. Chapter 16, 163-175 pp.; *In* M. Reed and S. Johnsen [Eds.] Produced Water 2: Environmental Issues and Mitigation Technologies. Plenum Press, New York.

Neff, J., Rabelais, N.N., and Boesch, D.F. 1987. Offshore oil and gas development activities potentially causing long-term environmental effects. Chapter 4, 149-173 pp.; *In* D.F. Boesch and N.N. Rabelais [Eds.] Long-Term Environmental Effects of Offshore Oil and Gas Development. Elsevier Applied Sci. London.

Neff, J.M., Bothner, M.H., Maciolek, N.J., and Grassle, J.F. 1989. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. Marine Environmental Research, 27: 77-114.

Nettleship, D.N., and Birkhead, T.R. [Eds.]. 1985. The Atlantic Alcidae. Academic Press, New York: 574 p.

Northeast Region Essential Fish Habitat Steering Committee. 2002.

O'Boyle, R., Sinclair, M., Keizer, P., Lee, K., Ricard, D., and Yeats, P. 2004. Indicators for ecosystem-based management on the Scotian Shelf: Bridging the gap between theory and practice. Can. Sci. Advis. Secr. Res. Doc. 2004/076.

Osenberg, C.W., Schmitt, R.J., Holbrook, S.J., and Canestro, D. 1992. Spatial scale of ecological effects associated with an open coast discharge of produced water, 387-402 pp.; *In* J.P. Ray and F.R. Engelhard [Eds.] Produced Water, Plenum Press, New York.

Parsons, J, and Associates. 1996. Oil based drilling muds environmental monitoring program at Cohasset. Shellfish Tainting Study-1993/95. Benthic Sampling Program-1993: 1-36.

Payne, J.F. 2003. PERD and understanding potential effects of oil development: Grand Banks experience. *In* D. Bancroft, R.A. Lake, S-L. Marshall and K. Lee [Eds] An Overview of Marine Environmental Research Pertaining to West Coast Offshore Oil and Gas Development. Can. Tech. Rep. Fish. Aquat. Sci. 2480.

Payne, J., Fancey, L., Andrews, C., Meade, J., Power, F., Leek, K., Veinott, G., and Cook, A. 2001. Laboratory exposures of invertebrate and vertebrate species to concentrations of IA-35 (Petro-Canada) drill mud fluid, production water and Hibernia drill mud cuttings. Can. Manuscr. Rept. Fish. Aquat. Sci. 2560.

Piper, D.J.W., and Campbell, D.C. 2002. Surficial geology of the Scotian Slope, eastern Canada. Geological Survey of Canada. Current Research 2002-E15.

Piper, D.J.W., Farr, J.A., and Shorr, A.N. 1985. Late quaternary slumps and debris flows on the Scotian Slope. Bulletin, Geological Survey of America. v. 96: 1508 – 1517.

Platt, T., Fuentes Yaco, C., and Frank, K.T. 2003. Spring algal bloom and larval fish survival. Nature 423: 398-399.

Pratt, J.R. 1994. Artificial habitats and ecosystem restoration: Managing for the future. Bulletin of Marine Science 55(2-3): 268-275.

Querbach, K., G. Maillet, P. Cranford, C. Taggart, K. Lee, and J. Grant. 2000. Toxicity of produced water to the early life stages of haddock, American lobster and sea scallop. In: Gordon, D.C., Jr., L.D. Griffiths, G.V. Hurley, A.L. Muecke, D.K. Muschenheim and P.G. Wells (eds.). 2000. Understanding the environmental effects of offshore hydrocarbon development. Can. Tech. Rep. Tech. Aquat. Sci. 2311.

Querbach, K., Maillet, G., Cranford, P.J., Taggart, C., Lee, K., and Grant, J. 2005. Potential effects of produced water discharges on the early life stages of three resource species, 343-372 pp.; *In* S.L. Armsworthy, P.J. Cranford, and K. Lee [Eds.] Offshore Oil and Gas Environmental Effects Monitoring. Approaches and Methodologies. Battelle Press. Columbus, Ohio.

Raimondi, P.T., and R.J. Schmitt 1992. Effects of produced water on settlement of larvae: Field tests using red abalone, 415-430 pp.; *In* J.P. Ray and F.R Engelhardt [Eds.] Produced Water: Technological/Environmental Issues and Solutions. Plenum Press, New York

Ray, J.P., and Engelhardt, F.R. [Eds.] 1992. Produced water: Technological/environmental issues and solutions. Plenum Press, New York.

Reed, M., and Johnson, S. [Eds.] 1996. Produced Water 2: Environmental Issues and Mitigation Technologies. Plenum Press, New York.

Rochet, M.J., and Trenkel, V.M. 2003. Which community indicators can measure the impact of fishing? A review and proposals. Can. J. Fish. Aquat. Sci. 60: 86-99.

Sameoto, D. 2004. Northwest Atlantic plankton trends 1959 to 2000. Can. Sci. Advis. Secr. Res. Doc. 2004/073: 12 p.

Sameoto, D,, and Cochrane, N. 1996. Euphausiids the on eastern continental shelf. CSAS Res. Doc. 1996/119: 12 p.

Sameoto, D.D., and Herman, A.W. 1990. Life cycle and distribution of *Calanus finmarchicus* in deep basins on the Nova Scotia shelf and seasonal changes in *Calanus* spp. Mar. Ecol. Prog. Ser. 66: 225-237.

Sameoto, D.D., and Herman, A.W. 1992. Effect of the outflow from the Gulf of St. Lawrence on Nova Scotia Shelf zooplankton. Can. J. Fish. Aquat. Sci. 49: 857-869.

Sankerelli, L., and Fader, G.B.J. 1999. The morphology of the eastern Scotian Shelf. Geological Survey of Canada, Open File #3741.

Schiff, K.C., Reish, D.J., Anderson, J.W., and Bay, S.M. 1992. A comparative evaluation of produced water toxicity, 199-208 pp.; *In* J.P. Ray and F.R Engelhardt [Eds.] Produced Water: Technological/Environmental Issues and Solutions. Plenum Press, New York.

Scott, J.S. 1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northw. Atl. Fish. Sci. 3: 29-39.

SOEP. 1996. Sable offshore energy project. Volume 3: Environmental impact statement. Secretariat, Joint Public Review/Sable Gas Projects, Halifax, N.S.

Southwood, T.R.E. 1988. Tactics, strategies and templates. Oikos 52: 3-18.

Stobo, W.T., Beck, B., and Horne, J.K..1990. Seasonal movements of grey seals (*Halichoerus grypus*) in the northwest Atlantic, 199-213 pp.; *In* W.D. Bowen [Ed.] Population Biology of Sealworm (*Pseudoterranova decipiens*) in Relation to its Intermediate and Seal Hosts. Can. Bull. Fish. Aquat. Sci. 222.

Swain, D.P., and Sinclair, A.F. 2000. Pelagic fishes and the cod recruitment dilemma in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 57: 1321-1325.

Tedford, T., Gonzalez, E., and Hannah, C.G. 2001. Bblt Version 3.1 User's Manual. Can. Tech. Rep. Hydrog. Ocean Sci. 213.

Thomson, D.H., Lawson, J.W., and Muecke, A. 2000b. Proceedings of a workshop to develop methodologies for conducting research on the effects of seismic exploration on the

Canadian east coast fishery. Halifax, Nova Scotia. 1-8 September 2000. ESRF Report No. 139. Calgary.

Thomson, D.H., Davis, R.A., Belore, R., Gonzalez, E., Christian, J., Moulton, V.D., and Harris, R.E. 2000a. Environmental Assessment of Exploration Drilling off Nova Scotia. Report to Mobil Oil Canada Limited and others, LGL Report No. TA 2281.

Thompson, J.H., and Bright, T.J. 1980. Effects of an offshore drilling fluid on selected corals, 1044-1078 pp.; *In* Symposium: Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Jan. 21-24, 1980, Lake Buena Vista, FL., Vol. 2. American Petroleum Institute, Washington, DC.

Tremblay, M.J., and Roff, J.C. 1983. Community gradients in the Scotian shelf zooplankton. Can. J. Fish. Aquat. Sci. 40: 598-611.

Trippel, E.A., Kjesbu, O.S., and Solemdal, P. 1997. Effects of adult age and size structure on reproductive output in marine fishes, 31-62 pp.; *In* R.C. Chambers and E.A. Trippel [Eds.] Early Life History and recruitment in fish populations. Chapman and Hall, New York.

Vandermeulen, H., and Cobb, D. 2004. Marine environmental quality: A Canadian history and options for the future. Oceans. Coast. Management 47: 243–256.

Verity, P.G., and Smetacek, V. 1996. Organism life cycles, predation, and the structure of marine pelagic ecosystems. Mar. Ecol Prog Ser 130: 277–293.

Waldron, D.E. 1982. Diet of the silver hake (*Merlucius bilinearis*) on the Scotian Shelf. J. Northw. Atl. Fish. Sci., 14: 87-101.

Waldron, D.E. 1988 Trophic biology of the silver hake (*Merlucius bilinearis*) population of the Scotian Shelf. Ph.D. thesis, Dalhousie University.

Walters, C., and Kitchell, J.F. 2001. Cultivation/depensation effects on juvenile survival and recruitment: Implications for the theory of fishing. Can. J. Fish. Aquat. Sci. 58, No. 1: 39-50.

Waring, G.T., Quintal, J.M., and Swartz, S.L. 2000. U.S. Atlantic and Gulf of Mexico marine mammal stock assessments -- 2000. NOAA Tech Memorandum

Watling, L., and Norse, E.A. 1998. Disturbance of the seabed by mobile fishing gears: A comparison to forest clear cutting. Conservation Biology 12 1180-1197.

Whitehead, H. 1996. Variation in the feeding success of sperm whales: Temporal scale, spatial scale and relationship to migrations. J. Anim. Ecol. 65: 429-438.

Whitehead, H., Bowen, W.D., Hooker, S.K., and Gowans, S. 1998. Marine mammals, 186-221 pp.; *In* W.G. Harrison and D.G. Fenton [Eds.] The Gully: A Scientific Review of its Environment and Ecosystem. Department of Fisheries and Oceans, Ottawa, Canada.

Wildish, D.J., and Stewart, P.L. 2004. A geographically-based, ecosystem management strategy for the offshore regions of the Scotian Shelf/Bay of Fundy. CSAS Res. Doc. 2004/012.

Wolfson, A., Van Blaricom, G., Davis, N., and Lwebel, G.S. 1979. The marine life of an offshore oil platform. Mar. Ecol. Prog. Ser. 1: 81-89.

Worm, B., and Myers, R.A. 2003. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. Ecology 84: 162-173.

Zakardjian, B., Sheng, J., Runge, J., McLaren, I., Plourde, S., Thompson, K.R., and Gratton, Y. 2003. Effects of temperature and circulation on the population dynamics of *Calanus finmarchicus* in the Gulf of St. Lawrence and Scotian Shelf: Study with a coupled, three-dimensional hydrodynamic, stage-based life history model. J. Geophys. Res. 108 (C11): 8016.

Zhou, S., Ackman, R.G., and Parson, J. 1996. Very long-chain aliphatic hydrocarbons in lipids of mussels (*Mytilus edulis*) suspended in the water column near petroleum operations off Sable Island, N.S., Canada. Marine Biology 126: 499-507.

Zwanenburg, K. 1998. Fish and selected invertebrates. *In* W.G. Harrison and D.G. Fenton [Eds.] The Gully: A Scientific Review of its Environment and Ecosystem. Can. Stock Assess. Secr. Res. Doc. 98/83.

Zwanenburg, K. 2000. The effects of fishing on demersal fish communities of Scotian Shelf. ICES Journal of Marine Science, 57: 503–509.

Zwanenburg, K. 2003. The Scotian Shelf, 75-91 pp.; *In* G. Hempel and K. Sherman [Eds.] Large Marine Ecosystems of the World – Trends in Exploitation, Protection and Research. Elsevier, New York.

Zwanenburg, K.C.T., and Bowen, W.D. 1990. Population trends of the grey seal (*Halichoerus grypus*) in eastern Canada. Can. J. Fish. Aquat. Sci. Bull. 222: 171-184.

Zwanenburg, K.C.T., Bowen, D., Bundy, A., Drinkwater, K., Frank, K., O'Boyle, R.N., Sameoto, D., and Sinclair, M. 2002. Decadal changes in the Scotian Shelf large marine ecosystem, 105-150 pp.; *In* K. Sherman and H.-R. Skjoldal [Eds.] Changing States of the Large Marine Ecosystems of the North Atlantic. Elsevier Science.

Appendix 1. Regional Work on Oil and Gas Issues to Date.

- A DFO research program has been carried out to determine the distribution of deepwater corals on the continental margin and as important elements on the continental slope.

- Class environmental assessment of exploration drilling off Nova Scotia (Thomson et al. 2000a).

- Class environmental assessment of seismic activity (Davis et al. 1998).

- Workshop on methodologies for studies of seismic impacts (Thomson et al. 2000b)

- SOEP Workshop on environmental effects in Nova Scotia Offshore (Gordon et al. 2000).

- Research studies on effects of seismic on snow crab (Christian et al. 2004) and experimental DFO study (DFO 2004b). Review of impacts of seismic on marine animals (DFO 2004a).

- Conference on environmental effects monitoring for offshore oil and gas (Armsworthy et al. 2005).

- The Gully Seismic Research Program of the Centre for Offshore Oil and Gas Environmental Research (COOGER) (Lee et al 2005).

- International workshop on oil-particle interactions (April 2000). Particles, both living and non-living, affect the fate and effects of oil spilled into the aquatic environment. The papers were published as a special issue of *Spill Science and Technology Bulletin* (Vol 8 (1), 2003.

- Modeling drill mud particulates in the benthic boundary layer (Hannah and Drodzowski in press).

- Impacts of drill wastes on sea scallop (e.g. Cranford and Gordon 1991, 1992);

- Impacts of drilling wastes on larval stages of scallops, lobster, and important fish species (Cranford et al. 1998a,b).

- In situ environmental monitoring tools for impacts of drilling wastes around rigs (Cranford, in press), and for sampling drilling mud wastes (Muschenheim et al. 1995).

- Habitat model for Scotian Shelf benthic ecosystems developed for RAP process (V. Kostylev, AGC).

Appendix 2. Science Requirements in Support of Oil and Gas Related Issues.

- Where possible, identify information gaps or methodologies that if known/applied would improve the state of our knowledge and ability to monitor/manage the effects of offshore oil and gas activities.

- *Research on impacts of drilling wastes on deepwater corals:* Presently there is no specific information and information must be derived from studies of shallow water corals, for which there is limited study. Impacts on corals could be severe if drilling wastes were toxic, because of the likely slow regrowth and sporadic recolonization.

- *Research on impacts of drilling wastes on resource species:* Impacts should be evaluated for Stimpson's Surf Clam and northern deepwater shrimp and possibly northern Propeller Clam.

- *Sable Island Ecosystem:* The proximity of the SOEP development to Sable Island and its associated shallow-water ecosystem is not typically highlighted because the Island is not used to support the offshore activities and because the hydrocarbon product (natural gas and condensate) is comparatively less harmful and intrusive than other hydrocarbons. The marine ecosystem of the waters around Sable Island has not been studied, despite the conservation significance of the island, although it may be productive, supporting as it does colonial seabirds and grey seal populations.

- Research on benthic community composition and dynamics on offshore banks where production is taking place to determine dominant processes and extent of effects.

- Impacts of buried flowlines, operating at elevated temperatures, on structure and dynamics of benthic communities.

- Habitat value of offshore structures. Determine types, seasonality, factors affecting distribution of marine fouling communities and associated invertebrates and fish. Some work on value of artificial reefs and reef balls in coastal areas is being conducted (e.g. Glyn Sharpe, Bedford Institute of Oceanography) whose findings could extend to offshore situations.